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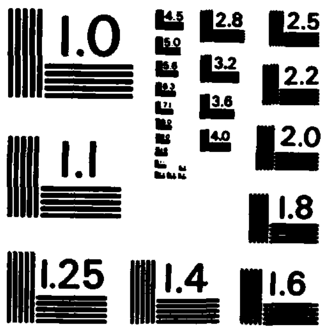

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A COMPARATIVE EVALUATION OF EMADS AND CONVENTIONAL ENGINE INSTRUMENTS

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ABSTRACT

A study was conducted to assess the performance benefits associated with the use of the General Electric Engine Monitoring and Display System (EMADS). An experiment was designed to compare pilot performance using both EMADS and conventional engine instruments. Data was collected from eight DC-10 qualified pilots having an average of over 13,000 hours of flight experience.

The flight task for each of the sixteen test trials consisted of engine startup, manual takeoff, and climbout to 5,000 feet in a fixed base simulator. In addition, a number of predefined engine related fault conditions were introduced at various points during the simulation, with the pilots being instructed to execute the appropriate corrective action.

For each of the fault monitoring tasks, performance (reaction time) with EMADS was as good or better than that resulting from the use of conventional instruments. Subjective input obtained from the pilots indicated a clear preference for EMADS. Recommendations are made regarding future research activity.

KEYWORDS

engines

simulation

displays

alerting

pilot performance

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INTRODUCTION

The continuing advancement of high-performance aircraft has brought with it an increasing degree of complexity in the physical operating system due to such factors as flight operation complexity, demands for improved safety, improved reliability, and more efficient operations. Such demands require the development of advanced concepts for status monitoring and information displays for aircraft systems. The excessive number of indicators and annunciators in the cockpit is rapidly approaching the saturation point in terms of crew capability to assimilate and assess the significance of indications, make decisions, and take appropriate action. Besides adding to crew workload, this proliferation of discrete annunciators is reducing the availability of installation space for equipment in the cockpit.

The development of advanced digital display technology for flight deck applications has received considerable attention in recent years. Manufacturers of aircraft and avionics equipment have allocated substantial research and development efforts toward improving cockpit efficiency through the use of electronic display media. In response to this need, a joint research effort was undertaken by General Electric (GE) and Douglas Aircraft Company (DAC) to develop an Engine Monitoring and Display System (EMADS). EMADS has been advanced as a viable alternative to the conventional electromechanical engine instruments presently being used in commercial aircraft. The specific purpose of EMADS is to provide the flight crew with displays for all engine management activities. It is also designed to provide engine maintenance and performance summaries for post-flight analysis.

Summary of Previous Developmental Efforts

The EMADS program was initiated in 1974. In 1975, system operating concepts and display requirements were evaluated and refined. The results were developed into system scenario formats for programming in the Digital Equipment and Technology Analysis Center (DETAC), located at Douglas Aircraft Company in Long Beach, California. Flow diagrams were completed and updated during the first quarter of 1976 and were

then used as the basis for development of functional system requirements, display and input requirements for continuous and discrete parameters. Completion of the DETAC simulation in 1977 provided candidate display formats, mode definition, and verification/refinement of crew-system interfaces. These results were then used by GE for software development and final completion of the hardware development and fabrication. A parallel effort was continued by GE to develop the engine model which was to be programmed into the Motion Base Simulator (MBS) computer. After the system was received, installed, and checked out on the MBS, ten DAC pilots participated in simulation runs using the procedure developed by DAC Human Factors Engineering. Results of these initial runs were used to modify the system software. Twenty additional simulation runs were performed using test pilots and flight engineers from DAC. Each pilot flew a partial flight scenario intended to exercise the major functions of EMADS. Following simulation trials, each subject participated in a debriefing session and completed a comprehensive questionnaire evaluating EMADS operational characteristics. Based on the judgments of these experienced pilots, EMADS offers the potential for significant reduction in cockpit workload from the effort required with conventional engine instruments.

In 1978, EMADS was evaluated by representatives from various airlines, military services, and regulatory agencies. A total of ninteen organizations participated in the demonstration which was conducted in the DAC MBS. The scenario provided an opportunity for "hands-on" familiarization with the EMADS control and display unit and demonstrated the full range of EMADS operational capabilities. Following the simulation, pilots viewed a demonstration of potential color-coding applications to the baseline monochromatic EMADS display formats. The overall pilot evaluation of the system was quite positive. Sixty-three percent (63%) of the pilots said that EMADS was superior to conventional dials. Another major strength of the EMADS system is its flexibility. Eight-three percent (83%) of customer pilots indicated that the design and operation of the system would readily accommodate changes in procedures and differences in operating methods across airlines.

In 1979, Douglas Aircraft sponsored a flight operations seminar at which EMADS was demonstrated to approximately one hundred forty-five pilots and other flight operations personnel. A total of twenty-two of these individuals completed and returned a questionnaire that addressed the relative merits of EMADS and conventional engine instruments. The respondents clearly felt that all rated EMADS features could reduce cockpit workload compared to conventional instruments. They also felt that EMADS would be more effective in facilitating quick and accurate responses to fault conditions. In general, they were quite impressed by the EMADS display characteristics, rating them from excellent to better than average in terms of brightness, contrast, display format, legibility, etc. About twenty-five percent (25%) of the respondents expected no significant transition problems between EMADS and conventional instruments. The remainder of the participants expected at least some transition problems,possibly during initial training. Overall, reaction to this demonstration was positive, although only fifteen percent (15%) of the observers completed and returned the questionnaire.

During the EMADS development program, a number of color coding applications have been suggested, some of which have been evaluated as part of the demonstration mentioned earlier. In general, participants reacted favorably to the use of color in the EMADS displays. As with any information display, color can provide a useful dimension if it is applied appropriately. If color is to be incorporated into the EMADS information display, it should be carried out in concert with existing guidelines for the applications of color to alert urgency levels (Berson, Po-Chedley, Boucek, Hanson, Leffler, and Wasson, 1981; Society of Automative Engineers, 1980).

Study Objective and Experimental Hypotheses

The primary purpose of the present study was to provide an objective evaluation of EMADS and conventional instruments. Several key questions were addressed in order to determine if EMADS is as good as or better than the present system. A comparison was made to determine pilot performance characteristics using EMADS and conventional instruments

during normal operations and also in identifying and correcting faults during various flight phases. While all areas of aircraft operations were investigated, the focus of this study was directed toward monitoring preflight, takeoff, and inflight operations.

Both subjective and objective data were collected. Subjective data was acquired by means of a questionnaire administered after completion of the test profile. Objective performance data was also collected to compare EMADS and conventional instruments under controlled experimental treatment conditions. In preflight, under normal conditions, response times were recorded in terms of total time to start engines. Both detection and response times were collected for preflight fault monitoring activity. For the normal operations portion of the takeoff flight segment, performance level was determined by the pilot's ability to accurately set the throttles to the appropriate N_1 command value. After takeoff and during the climb segment of the flight, faults were introduced to determine which display system is most conducive to optimal pilot performance. Auxiliary faults were also incorporated during various segments of the flight to extend the pilots point of focus. A detailed description of each of these treatment conditions is contained in the following section of this report. From the questions that have been raised in the preceding section the following hypotheses were derived:

Hypothesis 1 - EMADS will be as good as or better than conventional instruments in minimizing response time for normal start procedures.

Hypothesis 2 - EMADS will be as good as or better than conventional instruments on throttle setting accuracy relative to the mean N_1 value at 80 knots and at V_1 under normal takeoff operations.

Hypothesis 3 - EMADS will be as good as or better than conventional instruments in terms of time required for fault detection.

Hypothesis 4 - EMADS will be as good as or better than conventional

instruments in terms of total response time required for fault detection.

Hypothesis 5 - EMADS will be as good as or better than conventional instruments in terms of fuel expenditure during takeoff -- normal operations.

Hypothesis 6 - EMADS will be as good as or better than conventional instruments in terms of flight task performance.

METHOD

Pilot Sample

A total of nine pilots participated in the study, having an average of 13,875 hours of flight experience. American, Continental, Western, and United Airlines were each represented by a management level pilot with the remainder representing the Douglas flight test organization. To maximize the effectiveness of the experimental design, data from eight of these pilots (four airline and four DAC) was used in the objective analysis while all nine pilots were represented in the debriefing questionnaire analysis.

Facility

Primary experimental investigation took place in the DAC Motion Base Simulator (MBS). The MBS employs a six axis motion system and a high fidelity terrain model for external visual reference. Since motion cues were not required for this study, the simulator was operated in a fixed base mode. Depending on the test conditions, the simulator was configured with either EMADS or conventional instruments. Each of these configurations can be seen in Figure 1 and Figure 2. Other than the engine instrument configuration and the EMADS keyboard mounted on the forward pedestal, the cockpit layout was the same for all test conditions. Active displays and controls used in the study included the following:

1. Control wheel and column
2. Trim switches
3. Fault detection switch (mounted on control wheel)
4. ADI, HSD, altimeter, VSI, IAS
5. Vertical speed wheel and control switch
6. APU isolation value
7. Overide/airstart switch
8. Landing gear lever
9. Flap/slat controls
10. Stabilizer position indicator
11. Parking brake
12. Master caution light

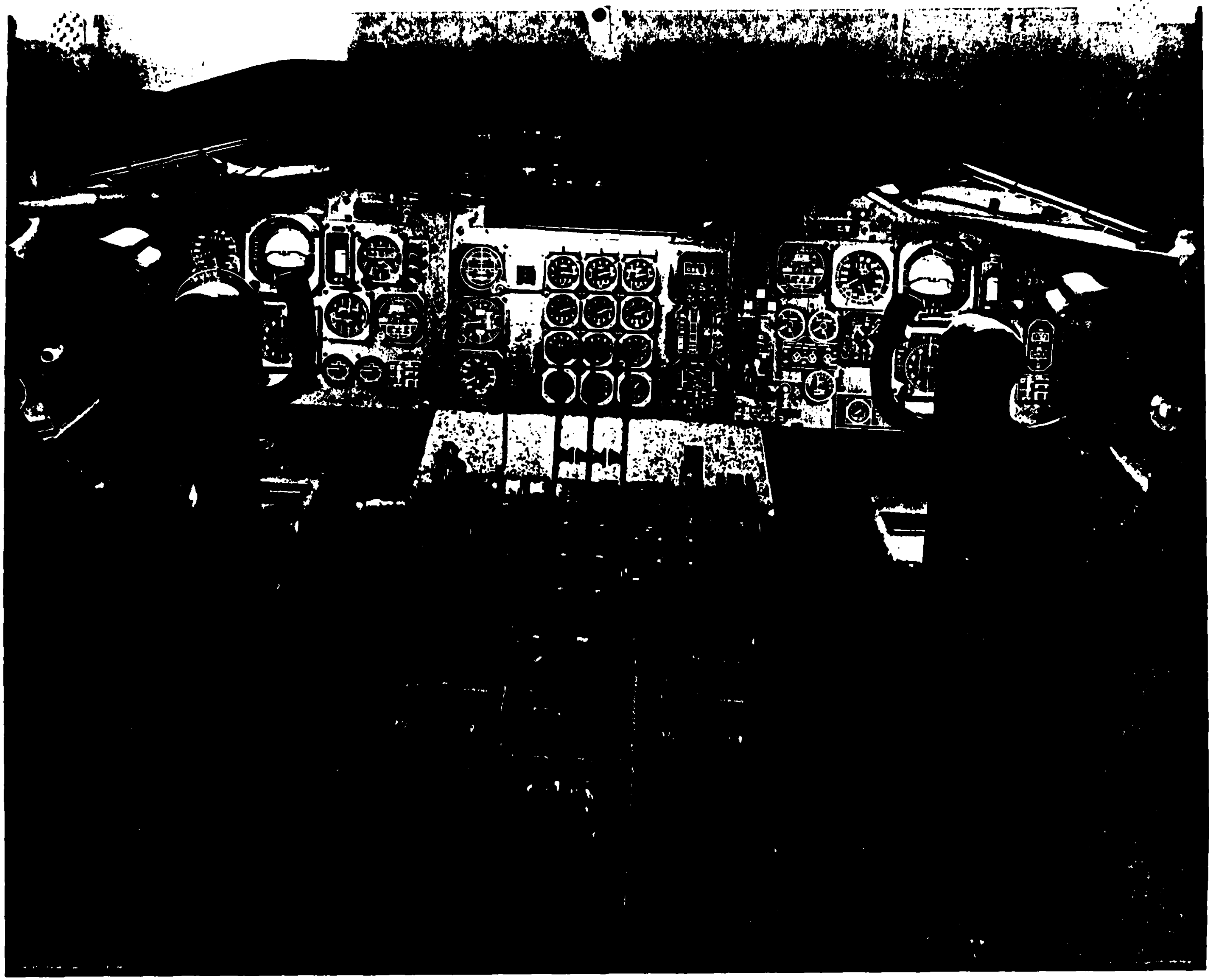


FIGURE 1. CONVENTIONAL INSTRUMENTATION

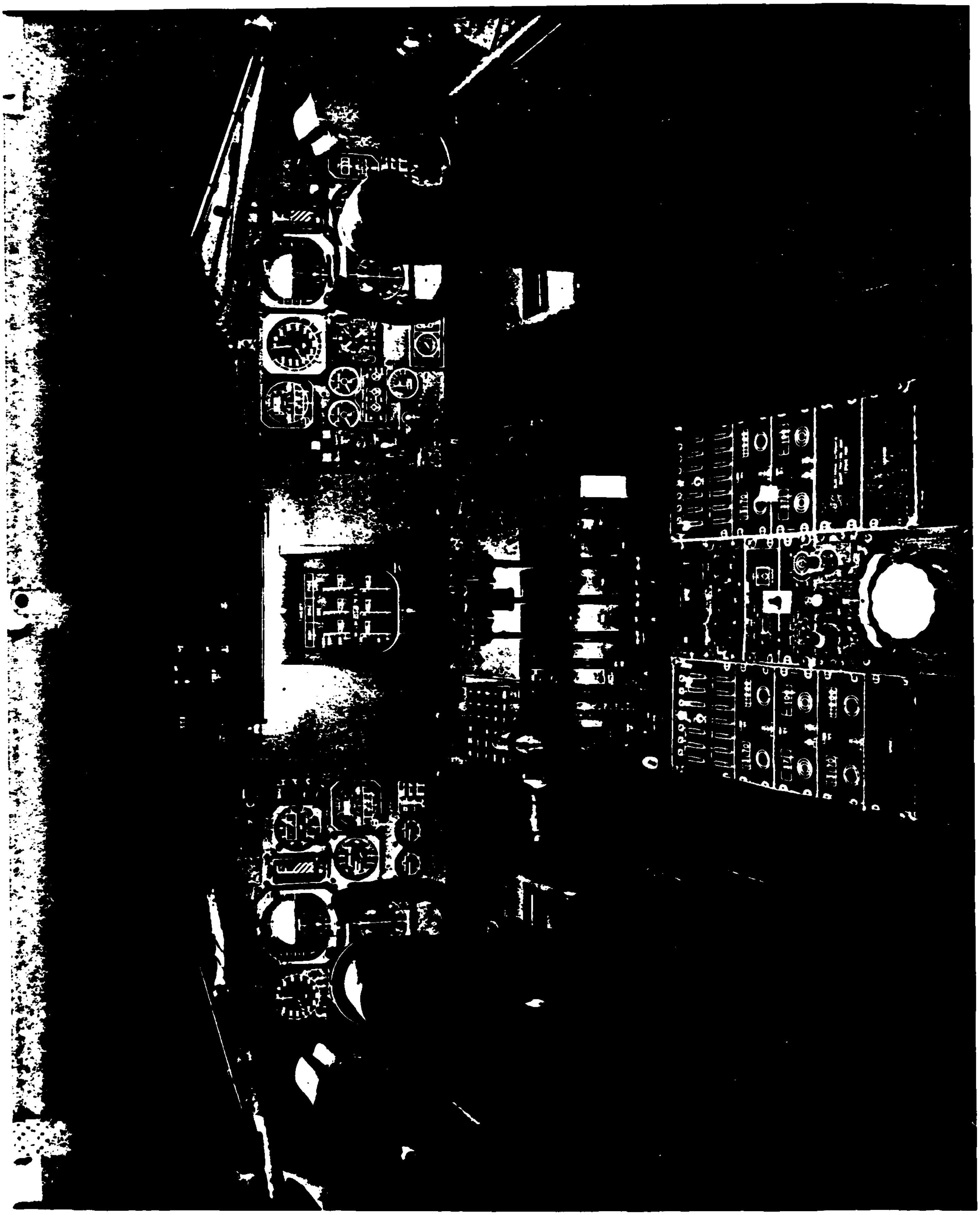


FIGURE 2. EMADS

13. Overhead fault annunciator and correction panel
14. EMADS control panel
15. Engine instruments
16. Fuel levers, start switches, and throttles

The simulator cockpit was designed to represent that of a three engine wide body aircraft. The general control/display arrangement was similar to that of a DC-10, as were the aircraft handling qualities. Pilots were told in the pretest briefing, however, that these similarities were coincidental.

In an effort to measure the attention-getting value of the two display types, the auto-pilot disconnect switch was made to function as a fault detection device. Pilots were instructed to depress this switch immediately after they detected the existence of an abnormal condition. Other than this modification, all displays and controls were representative of standard flight deck equipment.

For this study, the simulator was configured to accommodate a pilot, a first officer, and two experimenters. A special control panel and multichannel communication system allowed one of the experimenters to exercise control over the test environment while the other experimenter interacted with the pilot (test subject) and co-pilot. Communication headsets were provided for both pilots and experimenters. Each was tied into an audio-cassette taping system designed to record intracockpit conversation for subsequent analysis. The experimenters communication systems were tied into three additional remote locations where support personnel were stationed to receive and transmit pertinent information.

Flight Scenario

To make a discussion of the experimental design more meaningful, a description of the flight scenario used for each test run is in order. The basic flight profile can be seen in Table 1. The flight plan consisted of a modified noise abatement takeoff and climbout to 5,000 feet. A pilot from the Douglas Aircraft Flight Operations group participated as a co-pilot, and assisted in such tasks as gear retraction, V-speed callout and flap/slat retraction. The co-pilot did not assist in the fault correction or flight tasks.

TABLE 1

FLIGHT PROFILE FOR EMADS - CONVENTIONAL INSTRUMENTS COMPARATIVE ANALYSIS

TAKEOFF MAINTAIN RUNWAY HDG UNTIL 2,000 FEET (HDG 000°)

REDUCE TO CLIMBTHRUST AT 2,000 FEET (103.3% N_1)

MAINTAIN V_2 + 10 UNTIL 3,000 FEET

AT 3,000 FEET REDUCE VERTICAL SPEED TO 1,000 FEET/MINUTE

CONTINUE AT CLIMBTHRUST UNTIL CLEANUP IS COMPLETE

FLAP RETRACT (181 KTS)

SLAT RETRACT (299 KTS)

CONTINUE AT CLIMBTHRUST TO 5,000 FEET

After the engines were started and set at ground idle, the aircraft was positioned at the foot of the simulated runway. After takeoff, at an altitude of 2,000 feet, the pilot was instructed to reduce from takeoff to climb thrust. The co-pilot advised the pilot when the simulator was approaching 2,000 feet so that the thrust value could be adjusted. The co-pilot also advised the pilot when the simulator neared 3,000 feet and, on command, reduced the vertical speed to the appropriate level. In addition, the co-pilot retracted the flaps and slats on the pilots command.

Experimental Design

The study was designed to assess a wide range of EMADS operating characteristics. Therefore, a number of subexperiments were conducted serially, with each phase of activity during a particular test trial contributing data to one of five separate experiments. Each experiment was designed to comparatively analyze EMADS and conventional instruments relative to the following scheme:

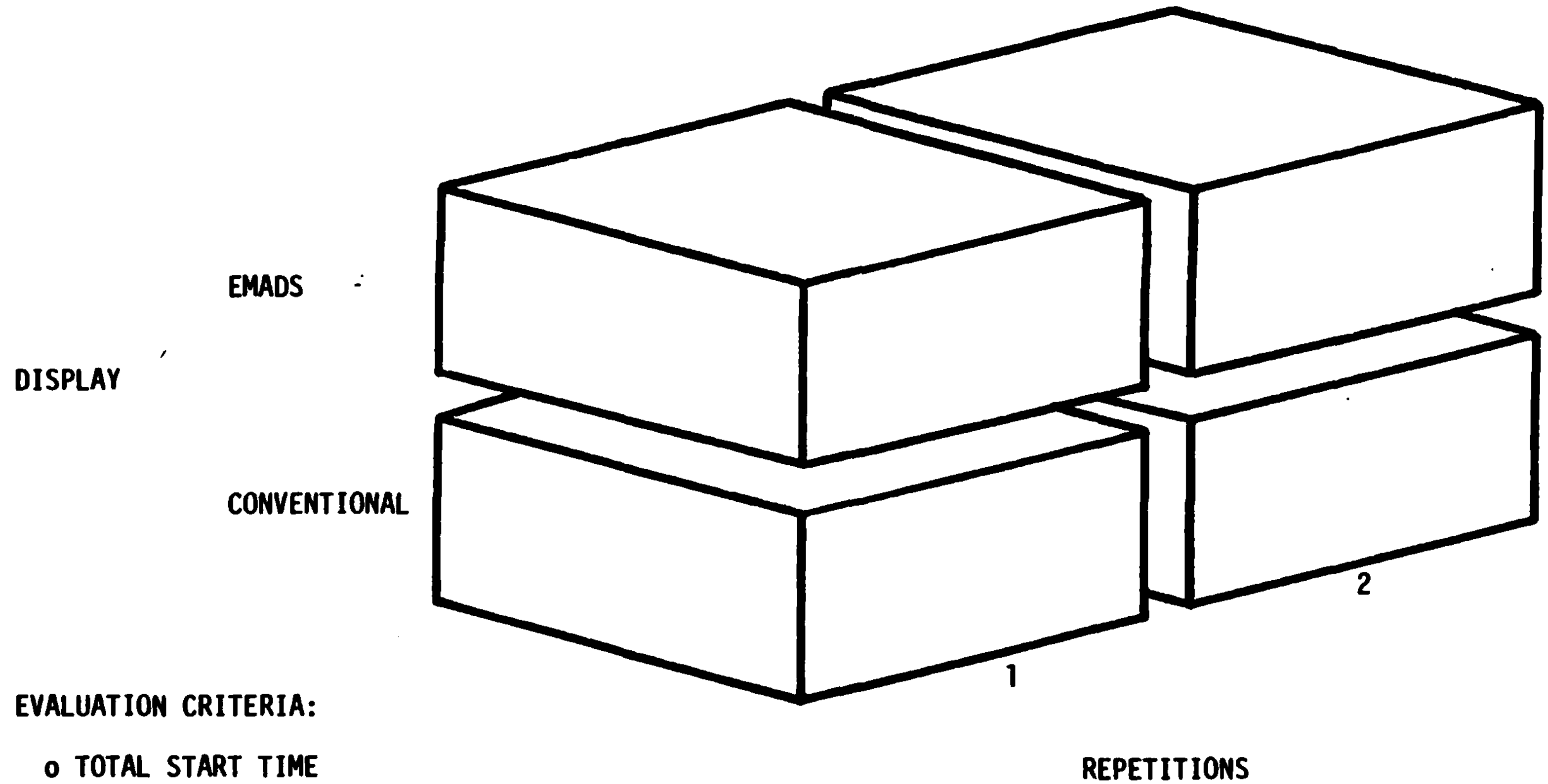
1. Preflight - Normal operations
2. Preflight - Fault monitoring
3. Takeoff - Normal operations
4. Takeoff - Fault monitoring
5. Inflight - Fault monitoring

Each subexperiment will first be described separetely; this will be followed by a description of the procedure used to meet the objectives of each experiment by conducting sixteen test trials. Half of the trials included engine startup and all involved the flight profile shown in Table 1.

Preflight: Normal Operations

This experiment was designed to assess the rapidity with which the engines could be started using EMADS and conventional instruments. Figure 3 illustrates the experimental design, where each pilot started all engines twice with both EMADS and conventional instruments. No faults were introduced during these trials so that a precise measurement

COMPARATIVE EVALUATION OF EMADS AND
CONVENTIONAL ENGINE INSTRUMENTS:
PREFLIGHT - NORMAL OPERATIONS



EVALUATION CRITERIA:

- o TOTAL START TIME
- o PILOT PREFERENCE

FIGURE 3

of total start time could be obtained. Start time was defined as the interval between the depression of the start switch for the first engine and the point at which the third engine was at ground idle (25% N_1). These four trials were interspersed among trials where faults were introduced during the engine-start sequence.

Preflight: Fault Monitoring

The purpose of this experiment was to assess the relative effectiveness with which pilots could detect and correct power plant problems during the start sequence using EMADS and Conventional Instruments. Figure 4 represents a complete factorial design where each pilot was exposed to all treatment conditions.

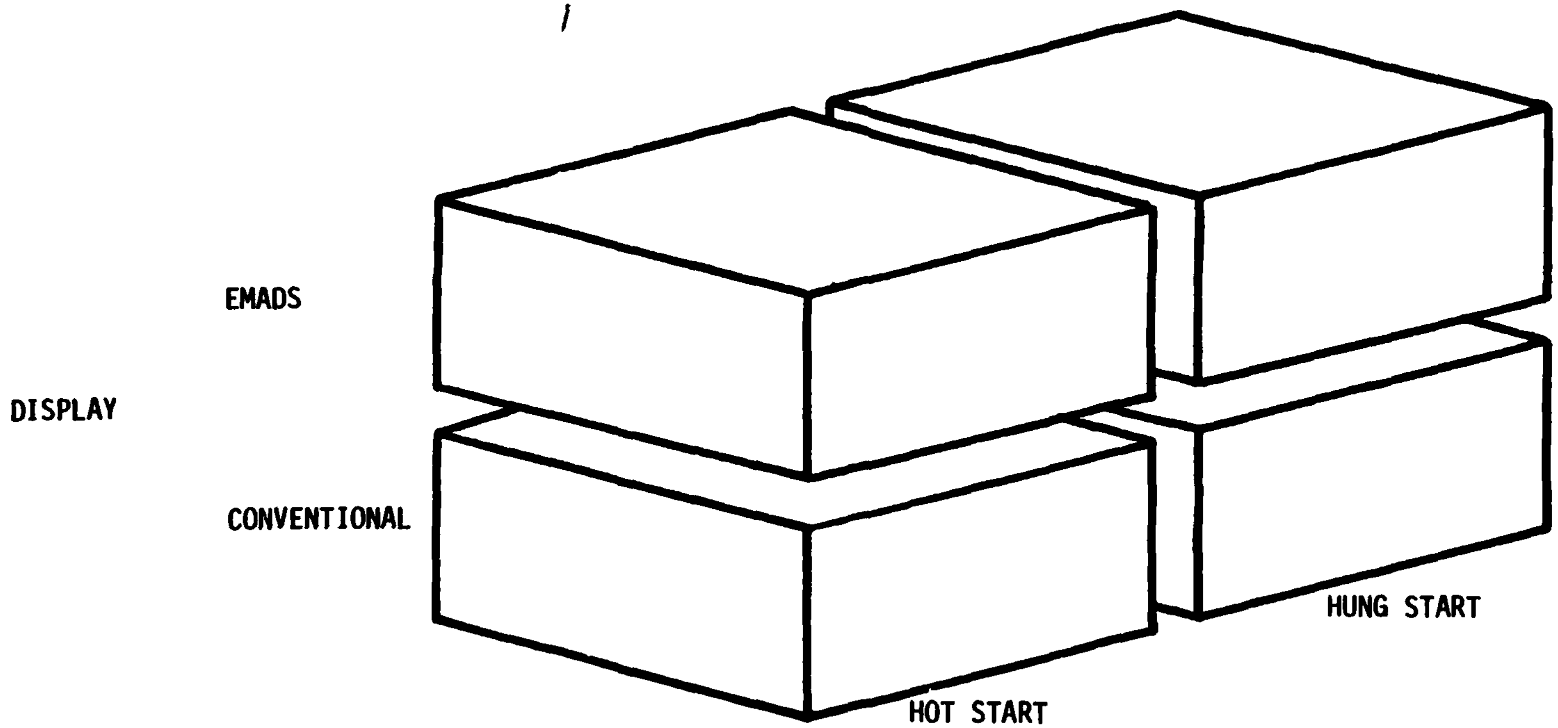
Of the sixteen test trials, eight involved the complete start sequence for the three engines while, in the remainder, the simulator was set at the foot of the runway (with all engines at ground idle), ready for takeoff.

During the engine start procedure for a particular trial where EMADS or conventional instruments were used, either a hot or hung start was introduced in one of the engines. The definitions and appropriate corrective actions for these faults as well as those introduced during other flight phases are provided in Table 2. During the engine start segment of each trial, a maximum of one and a minimum of zero faults were introduced.

Takeoff - Normal Operations

This experiment was designed to measure the efficiency and accuracy with which the pilots operated the engines during the takeoff roll. As illustrated in Figure 5, a five way design was employed with two levels of each independent variable. Repeated measures were obtained on four of these variables with the runway visual range (RVR) serving as a grouping variable; each pilot was exposed to all levels of the repeated measures variables while they were exposed to only one level of the grouping variable. In this way, four of the pilots were faced with a 700 foot RVR while the remainder were provided with a visual range of 2,400 feet.

COMPARATIVE EVALUATION OF EMADS AND CONVENTIONAL ENGINE INSTRUMENTS: PREFLIGHT - FAULT MONITORING



EVALUATION CRITERIA

- o DETECTION TIME
- o RESPONSE TIME
- o PILOT PREFERENCE

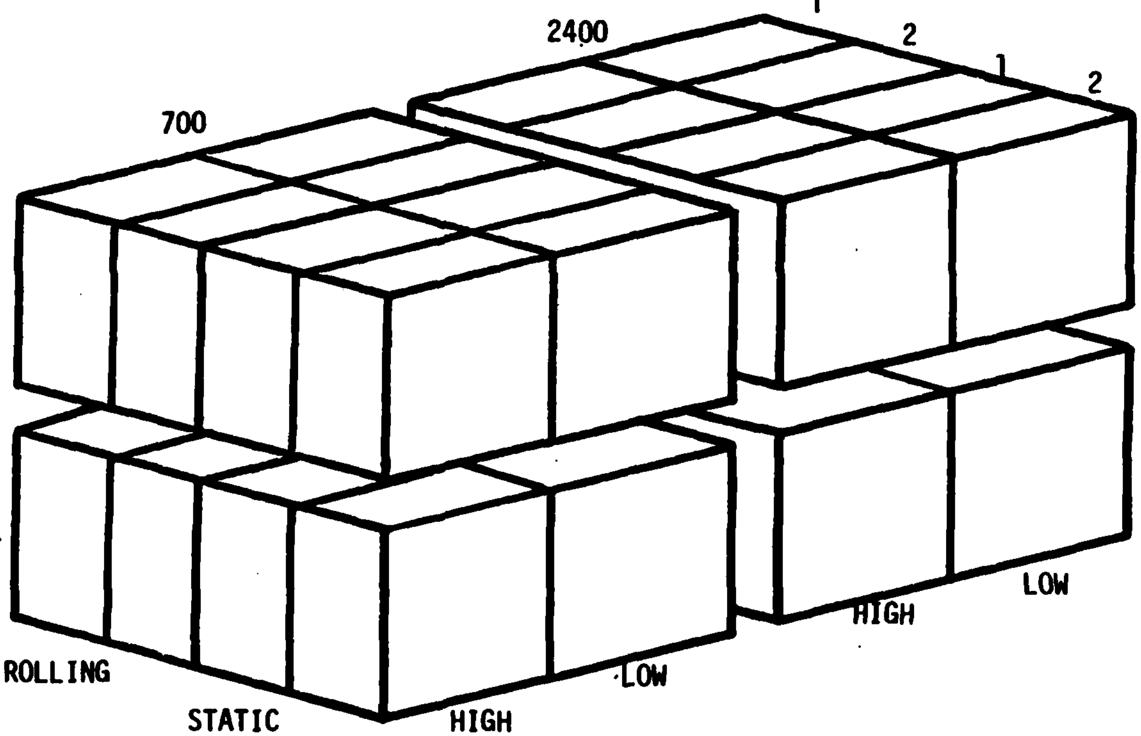
FIGURE 4

TABLE 2

FAULT CORRECTION PROCEDURE

FAULT	DEFINITION	CORRECTIVE ACTION
A. HUNG START	EGT < 200° AFTER 25 SEC	DETECT, FUEL LEVER OFF, AFTER 30 SEC, PULL ST. SWITCH, START ENGINE
B. HOT START	EGT > 750° FOR 40 SEC OR EGT > 250°/ SEC AT 20 SEC AFTER FUEL LEVER ON	DETECT, FUEL LEVER OFF, MOTOR 30 SEC, PULL ST. SWITCH, START ENGINE
C. N_1 OR EGT EXCEEDANCE	N_1 116% N_1 EGT > 875°	DETECT, PULL THROTTLE QUICKLY, BACK ALMOST TO IDLE AND THEN BACK TO NORMAL POSITION
D. FLAMEOUT	ONE N_1 > 11% LESS THAN OTHER N_1 WITH AT LEAST ONE N_1 AT 70%	DETECT, PUSH OVERRIDE/ AIRSTART SWITCH TO ON POSITION
E. AUXILIARY FAULTS	MASTER CAUTION ON AND OVERHEAD ANNUNCIATOR ON 1. SELECT FLAP LIMIT OVRD 2. UPPER YAW DAMP INOP 3. PNEU TEMP HIGH 4. R WINDSHIELD ANTI-ICE INOP	DETECT, DEPRESS OVERHEAD ANNUNCIATOR SWITCH

COMPARATIVE EVALUATION OF EMADS AND
CONVENTIONAL ENGINE INSTRUMENTS:
TAKEOFF - NORMAL OPERATIONS



EVALUATION CRITERIA:

- o MEAN N_1 SETTING - 80 KTS
- o MEAN N_1 SETTING - V_1
- o Pilot Preference

FIGURE 5

Depending on the RVR employed, it was expected that pilots would spend more or less time in the "heads-up" position. It was further hypothesized that pilots would perform better (in terms of power setting accuracy) in the head-up position using EMADS because the display provides a positive indication for out-of-tolerance conditions.

All pilots participated in eight trials with EMADS and eight with conventional instruments. In addition, half the trials for each pilot were initiated with a static takeoff where the power was set before the parking brake was released. The remainder were started with a rolling takeoff where the parking brake was released and the power was set during the takeoff roll.

An interactive effect was expected where better power setting performance would result from use of EMADS during a rolling takeoff while no difference between the two systems would be found during static takeoffs. This expectation was born out of the fact that EMADS provides a discrete cue when the N_1 thrust value is within one percent of the command parameter. During rolling takeoffs, the pilots were forced to divide their time between control of the aircraft and accurate power setting. The N_1 target value was either high (111.0% N_1) or low (108.3% N_1) for each trial. The high value represented normal takeoff thrust while the lower value represented the power requirements for a derated takeoff. It was expected that pilots would tend to undershoot the high N_1 command value more with conventional than with EMADS. Without the direct cue provided with EMADS, it was felt that pilots would be somewhat conservative to avoid overboosting the engines. Finally, each pilot participated in two repetitions of each experimental condition.

Standard DC-10 operating procedures specify that takeoff power should be set by the time the aircraft reaches 80 knots. To measure the relative ease with which takeoff power could be set with EMADS and conventional instruments, at 80 knots the N_1 value for each engine was recorded in system software for subsequent analysis. This provided an index of the pilots ability to accurately set the power while maintaining safe control of the aircraft with each engine display system. Also, by recording the mean N_1 setting at V_1 for each pilot, it was possible to

determine how much throttle movement occurred after 80 knots with each display system; the difference between the N_1 values at 80 knots and V_1 representing the degree to which the power was adjusted after 80 knots.

As fuel costs rise, so too does the need to judiciously monitor consumption during all phases of flight. Since a significant amount of fuel is required to allow the aircraft to become airborne, it was decided that fuel consumption per hour and total fuel usage would be monitored for each treatment condition during the takeoff roll. These measurements were used as indices of fuel savings as a function of display type, with the remaining treatment conditions providing interactive effects.

Takeoff - Fault Monitoring

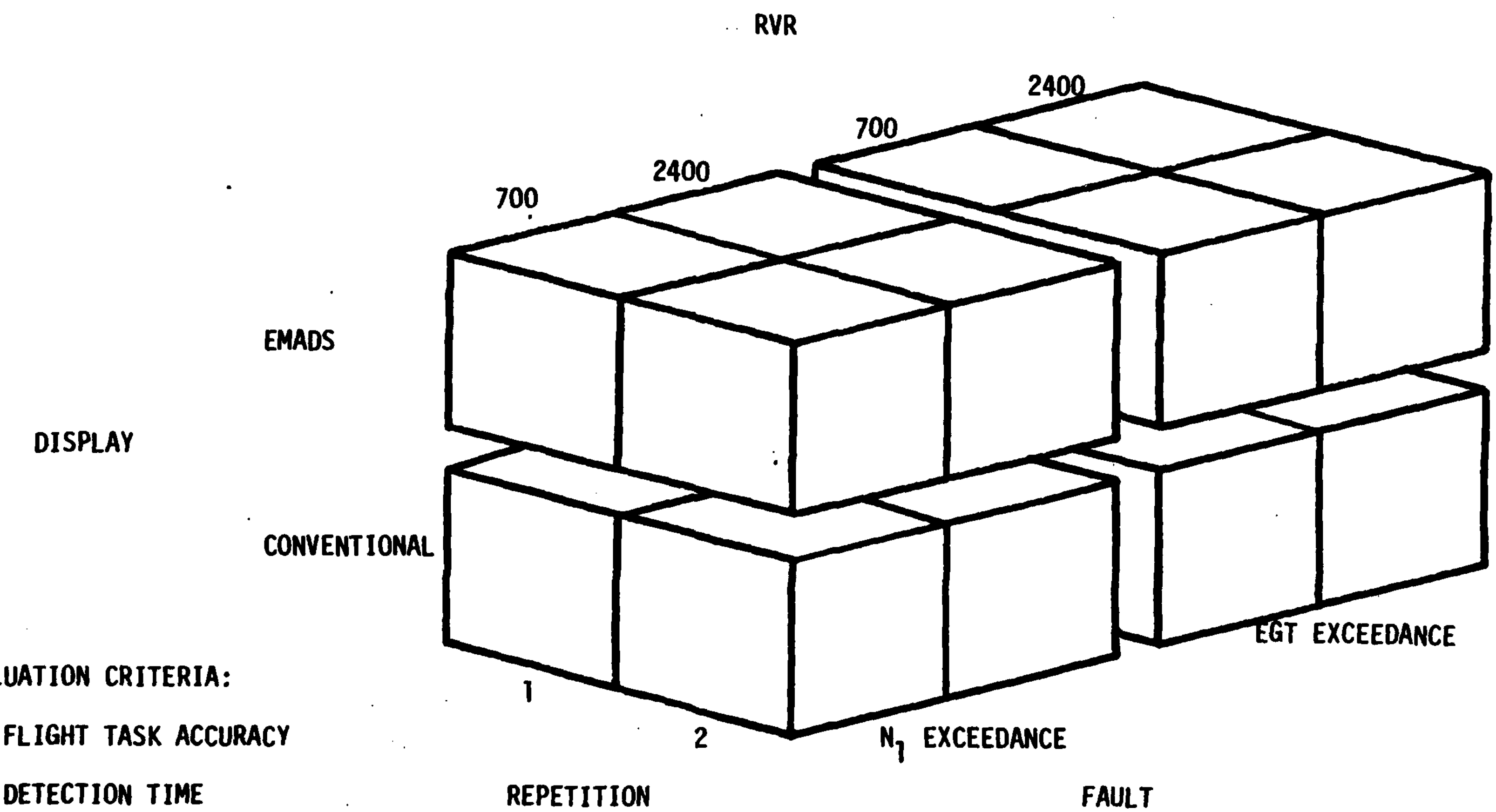
This experiment was designed to measure the degree to which pilots could detect and correct failures while safely controlling the aircraft after rotation. As with the previous experiment, RVR was employed as a grouping variable with repeated measures on the three remaining variables (Figure 6). For eight of the sixteen trials, an N_1 or EGT exceedance was introduced somewhere between ten and nineteen seconds after rotation.

The definitions and corrective actions associated with these faults can be seen in Table 2. Pilots were instructed to correct the problem while maintaining safe control of the aircraft. For a period of ten seconds beginning at the onset of the fault, heading error (in degrees) was recorded at a rate of twenty samples per second. This provided a measure of the pilots' ability to maintain control of the aircraft while engaged in fault correction activities. The time to detect and correct each fault was also recorded as was the degree or percent of exceedance. These represented measures of potential engine damage caused by failure to correct the faults in an expedient manner.

Inflight - Fault Monitoring

The last experiment was similar to that involving fault monitoring after rotation. The primary differences centered around the faults and their timing, as illustrated in Figure 7. As with the previous experiment, the pilots were divided into two groups of four, being exposed either to a

COMPARATIVE EVALUATION OF EMADS AND
CONVENTIONAL ENGINE INSTRUMENTS:
TAKEOFF FAULT MONITORING

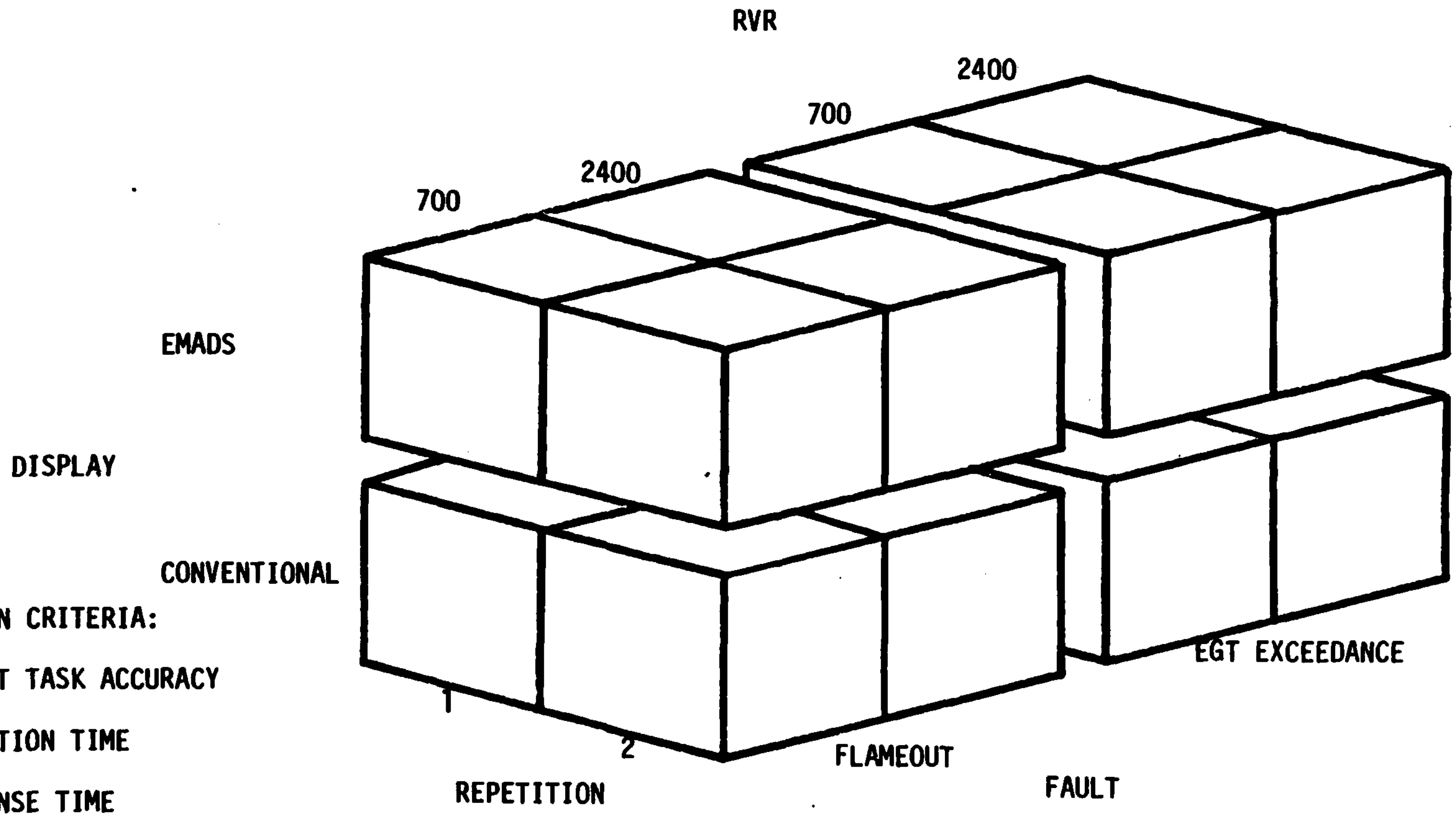


EVALUATION CRITERIA:

- o FLIGHT TASK ACCURACY
- o DETECTION TIME
- o RESPONSE TIME
- o PER CENT EXCEEDANCE
- o PILOT PREFERENCE

FIGURE 6

COMPARATIVE EVALUATION OF EMADS AND
CONVENTIONAL ENGINE INSTRUMENTS:
INFLIGHT FAULT MONITORING



EVALUATION CRITERIA:

- o FLIGHT TASK ACCURACY
- o DETECTION TIME
- o RESPONSE TIME
- o PERCENT EXCEEDANCE
- o PILOT PREFERENCE

FIGURE 7

700 or 2,400 foot RVR. Again, half the trials for each pilot were run with EMADS and the remainder with conventional instruments. Also, pilots were exposed to two repetitions of each fault; during eight of the sixteen test trials, either an engine flameout or EGT exceedance was introduced at some point between five and twenty seconds after the simulator reached 3,000 feet. The definitions and corrective procedures for these faults are contained in Table 2. The evaluation criteria were the same as those used in the previous experiment (Takeoff: Fault Monitoring).

Auxiliary Fault Monitoring

In addition to the engine faults that were introduced during each trial, a number of non-engine-related faults were presented at various times during the flight. These faults were annunciated by a master caution light and on an annunciator matrix which was located on the forward overhead panel. These conditions were introduced to expand the pilot's eye reference scan to include other areas of the cockpit typically viewed during abnormal operations. The faults employed included the following:

1. Select flap limit override
2. Upper yaw damper inoperative
3. Pneumatic temperature high
4. Right windshield anti-ice inoperative

The corrective action required for each of these faults is shown in Table 2.

Trial Assignments

In an effort to consolidate the activities required to obtain the necessary data for each experiment, a series of sixteen test trials or "cells" were designed such that all experimental objectives could be met in a reasonable length of time. As can be seen in Table 3, each cell represents a unique combination of variables for each experiment. Table 4 provides an explanation of the information corresponding to each flight phase for Cell 2.

				PRE-FLIGHT	TAKEOFF NORMAL		TAKEOFF FAULT		INFLIGHT ENG. FAULT		INFLIGHT AUX. FAULT	
RUN NUMBER	RVR 1 = 700 2 = 2,400	CELL	DISPLAY SYSTEM E: EMADS C: CONVENTIONAL	0 = NO FAULT 1 = HOT START 2 = HUNG START	T/O STRATEGY 1: ROLLING T/O 2: STATIC T/O	TARGET N1 VALUE 1: LOW 2: HIGH	T/O 0: NO FAULT 1: N_1 EXCEEDANCE 2: EGT EXCEEDANCE	TIME OF T/O FAULT 1: VR + 10 SEC 2: VR + 13 SEC 3: VR + 16 SEC 4: VR + 19 SEC	0: NO FAULT 1: FLAMEOUT 2: EGT EXCEEDANCE	TIME OF INFLIGHT FAULT 1: 3,000 FT + 5 SEC 2: 3,000 FT + 10 SEC 3: 3,000 FT + 15 SEC 4: 3,000 FT + 20 SEC	1: SEL FLAP LIM OVRD 2: UPPER YAW DAMP 3: PNEU TEMP HIGH 4: R WIND ANTI-ICE	TIME OF AUX. FAULT 1: VR + 10 SEC 2: 3,000 FT + 10 SEC 3: 4,000 FT + 5 SEC 4: 4,000 FT + 15 SEC
		1	E	0	1	1	1/1	1	1/2	1		
		2	E	2/3	1	1	0		2/3	2	1	1
		3	E	1/2	1	2	2/1	2	0			
		4	E	0	1	2	0		0		2	2
		5	E		2	1	2/2	3	0			
		6	E		2	1	0		2/1	3	3	3
		7	E		2	2	1/2	4	0			
		8	E		2	2	0		1/2	4	4	4
		9	C	0	1	1	1/3	1	1/3	1		
		10	C	2/1	1	1	0		2/2	2	1	1
		11	C	1/2	1	2	2/3	2	0			
		12	C	0	1	2	0		0		2	2
		13	C		2	1	2/1	3	0			
		14	C		2	1	0		2/3	3	3	3
		15	C		2	2	1/2	4	0			
		16	C		2	2	0		1/2	4	4	4

TABLE 3

FAULT DISTRIBUTION AND TIMING FOR EACH TRIAL

				PRE-FLIGHT	TAKEOFF NORMAL		TAKEOFF FAULT		INFLIGHT ENG. FAULT		INFLIGHT AUX. FAULT	
RUN NUMBER	RVR 1 = 700 2 = 2,400	CELL	DISPLAY SYSTEM E: EMADS C: CONVENTIONAL	0 = NO FAULT 1 = HOT START 2 = HUNG START	T/O STRATEGY 1: ROLLING T/O 2: STATIC T/O	TARGET N_1 VALVE 1: LOW 2: HIGH	T/O 0: NO FAULT 1: N_1 EXCEEDANCE 2: EGT EXCEEDANCE	TIME OF T/O FAULT 1: V_R + 10 SEC 2: V_R + 13 SEC 3: V_R + 16 SEC 4: V_R + 19 SEC	0: NO FAULT 1: FLAMEOUT 2: EGT EXCEEDANCE	TIME OF INFLIGHT FAULT 1: 3,000 FT + 5 SEC 2: 3,000 FT + 10 SEC 3: 3,000 FT + 15 SEC 4: 3,000 FT + 20 SEC	1: PACK 3 OFF 2: CARGO DOOR 3: LANDING GEAR 4: HYDRAULIC FAILURE	TIME OF AUX. FAULT 1: V_R + 10 SEC 2: 3,000 FT + 10 SEC 3: 4,000 FT + 5 SEC 4: 4,000 FT + 15 SEC
		1	E	0	1	1	1/1	1	1/2	1		
		2	E	2/3	1	1	0		2/3	2	1	1

HUNG START

ENGINE # 3

ROLLING TAKEOFF

LOW TARGET N_1 VALUE

NO FAULT DURING TAKEOFF

EGT EXCEEDANCE

ENGINE # 3

INFLIGHT FAULT OCCURS 10 SECONDS AFTER AIRCRAFT REACHES 3000 FEET

SUPPLEMENTAL FAULT: PACK 3 OFF

SUPPLEMENTAL FAULT OCCURS 10 SECONDS AFTER AIRCRAFT REACHES 4000 FEET

TABLE 4

EXPLANATION OF FAULT DISTRIBUTION AND TIMING FOR CELL 2

Cells 5 through 8 and 13 through 16 represent trials where the simulator was reset at the foot of the runway with all engines at ground idle. No engine startup was required for these trials because all necessary data for the first two experiments was collected during the eight trials shown in Table 3 (Cells 1 through 4 and 9 through 12). During trials where faults were introduced, the engines where the failures occurred were selected at random. To avoid any systematic learning effects half the pilots completed Cells 1 through 8 first, followed by Cells 9 through 16. The remainder completed the sixteen trials in reverse order. A Latin Square design was used to counterbalance the order in which the cells were completed by each pilot for both EMADS and conventional instruments, thus allowing each pilot to complete the sixteen trials in a unique order (Appendix A).

Table 3 represents the actual trial assignment sheet used during the study. A separate assignment sheet was used for each pilot so that the run number corresponding to each cell and the RVR could be appropriately adjusted. As mentioned earlier, the counterbalancing scheme was such that all pilots would complete each cell as a different test run. Also, since the visibility conditions (700 or 2,400 foot RVR) were varied, space was allotted for this entry as well.

Procedure

A standard set of test procedures was developed to serve as a means to ensure continuity across pilots relative to information transfer and activity control during the study. A full day of testing lasted approximately six hours. The following are the activities that were carried out during each test session along with their timing. Each of these activities will be described briefly in the following pages with a more detailed description provided in Appendix B.

Activity	Cumulative Hours
1. Preflight briefing	0000 - 0030
2. Cockpit briefing	0030 - 0130
3. Practice trials	0130 - 0200
4. Test trials	0200 - 0245

5. System changeover 0245 - 0415
6. Briefing for second configuration and practice trials 0415 - 0500
7. Test trials for second configuration 0500 - 0545
8. Debriefing 0545 - 0615

Preflight Briefing

In most cases, the study session began at approximately 8:30 a.m. In one case, because of a particular travel schedule, the session began at 11:00 a.m. and concluded at approximately 5:00 p.m.

All pilots invited to participate were provided with literature that described the pertinent details of the study. They were also provided with an EMADS operators guide and an article that described earlier developmental work completed on the EMADS program. The first part of the preflight briefing was devoted to answering questions on this material. Following this, pilots were provided with a description of the days activities and the facility to be used. On days when EMADS was to be tested first, a videotape of a number of EMADS operating characteristics was presented. This lasted approximately twelve minutes, after which a brief discussion took place where pilots made comments on,and asked questions about EMADS. On days where EMADS was tested in the afternoon, the videotape was presented during the system changeover time. In either case, at the conclusion of the videotape, the cockpit briefing began in the flight simulator.

Cockpit Briefing

This period of time was structured to provide the pilot with hands-on familiarization in the test environment. Each of the following items or groups of items were discussed, a more detailed description of which can be found in Appendix B.

1. General cockpit configuration
2. Voice taping system
3. Active displays and controls
4. Simulator idiosyncracies
5. Visual scene

6. Flight plan
7. Co-pilot activities

Practice Trials

Prior to "flying" the simulator, pilots were familiarized with the engine instruments (EMADS or conventional) and given several opportunities to set takeoff power in the static configuration. This was done to provide a "feel" for the throttle dynamics relative to the information displayed on the instruments. At this point, pilots were given the opportunity to become familiar with the handling qualities of the simulator by excercising the flight plan. During these trials, no faults were introduced as the main objective was to master the flight task.

After the pilot was confortable with the flight scenario, definitions and illustrations were provided for all faults and the action required to correct them. At this point, a "walk through" was conducted where a number of test scenarios were completed such that the pilot would be exposed to all failure conditions that were to occur during the test session. During these trials, the pilot was cued by the experimenter just prior to the occurrence of each failure condition. This allowed the pilot to see exactly how the displays would appear as faults situations were developing. Cues were also provided, as necessary, for the corrective action. This entire sequence (presentation of all faults) was repeated with the experimenter providing no cues. This standardized practice scenario was designed to reduce the "warm-up" effects that generally accompany test designs that require subjects to perform in situations with which they are not familiar.

Test Trials

Depending on the engine display configuration installed for this portion of the test session, the pilot completed the first eight trials with either EMADS or conventional instruments. During this time, half of the required data for one pilot was collected.

System Changeover

After completing the test trials with the first display configuration, approximately ninety minutes were required to install the engine instruments for the afternoon test session. Part of this time was used for a lunch break while the remainder was used to begin the briefing for the afternoon activities. On days when EMADS was scheduled for the afternoon, part of this time was used to present the videotape described earlier, and to discuss the various EMADS operating modes.

Briefing for Second Display Configuration and Practice Trials

Because the new engine display configuration represented the only change in cockpit hardware, a majority of the briefing time was used to familiarize the pilot with this aspect of the test environment. Following this, the same series of familiarization and parctice trials used for the morning session was employed.

Test Trials

The eight trials required to obtain the remaining data were completed at this time. Except for the engine display configuration, all test parameters were the same as those used in the morning session.

Debriefing

After the final test trial, pilots were invited to a debriefing session held at a location outside the simulation facility. During this time, pilots were asked to complete a debriefing questionnaire which solicited their views on the relative merits of EMADS and conventional instruments with respect to a number of operational criteria. A copy of the debriefing questionnaire can be found in Appendix C. In addition, an informal discussion took place where relevant pilot comments were recorded for subsequent documentation.

RESULTS

Statistical Analysis Technique

An analysis of variance (BMDP2V) was performed on each of the following sets of data:

1. Preflight: Normal operations
2. Preflight: Fault monitoring
3. Takeoff: Normal operations
4. Takeoff: Fault monitoring
5. Takeoff: Degree of EGT and N_1 exceedance
6. Inflight: Fault monitoring
7. Inflight: Degree of EGT exceedance
8. Takeoff and inflight: Heading deviation

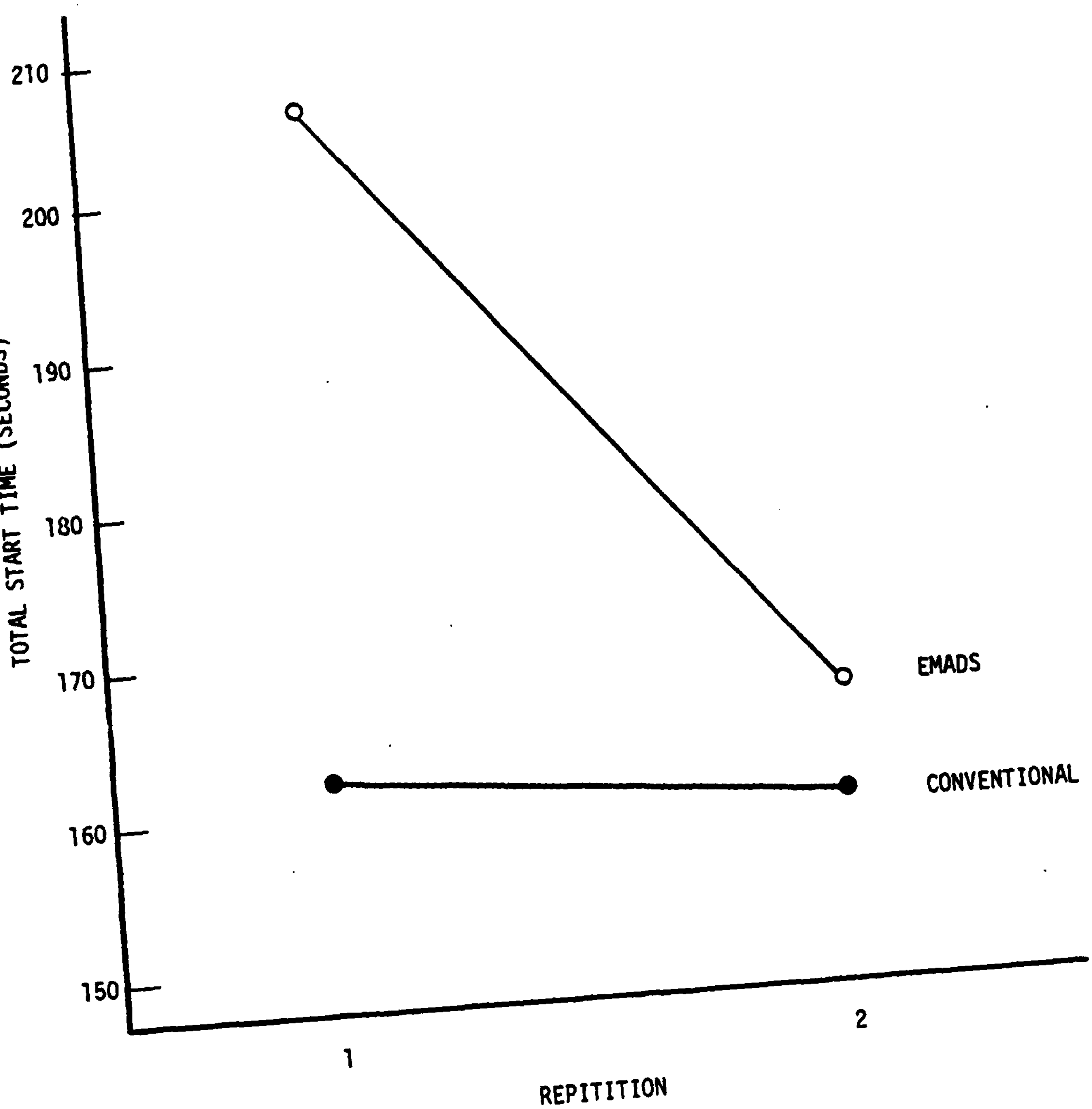
The results of each of these analyses are discussed in the following pages. Summary tables for each analysis can be found in Appendix D.

Preflight - Normal Operations

Eight of the sixteen test trials required the pilot to start each of the three engines using standard DC-10 procedures. For the remaining trials, the simulation was initiated at the foot of the runway with all engines at ground idle, ready for takeoff. During four of the engine startup trials (two each with EMADS and conventional instruments) no faults were introduced and the time required to start all engines was recorded. This time frame was initiated when the start switch for the first engine was depressed and ended when the third engine was at ground idle. This time segment was of interest because in some strategic missions such as military airlifts, the time required to prepare the aircraft for takeoff is of critical importance to operational success.

A two way analysis of variance with repeated measures was performed on the results, which exposed a significant reduction in total startup time when conventional instruments were used ($p<.05$). Figure 8 illustrates these results. This difference was partly due to the fact that the pilots were using slightly different cues with the two systems. EMADS provided a cue to start the next engine when the engine being

FIGURE 8. PREFLIGHT: NORMAL OPERATIONS
TOTAL START TIME



attended to reached twenty-five percent (25%) of its maximum N_1 thrust value. Shortly after receiving this cue, pilots would initiate the start procedure for the next engine. Although instructed that twenty-five percent (25%) N_1 represented normal ground idle with conventional instruments as well, a majority of the pilots also used cues provided by the digital readout of exhaust gas temperature (EGT) on the conventional display while, for the most part, they did not make use of this parameter on the EMADS display. Normal DC-10 procedures specify that an engine is considered as being at ground idle when the EGT reaches six hundred and two degrees Fahrenheit (602^{o}F.), which corresponds to an N_1 value of approximately twenty-one and eight tenths percent (21.8%). Although the simulation cockpit was not meant to represent that of a DC-10, it is understandable that the pilots would see the similarities and, at times, revert to procedural activities associated with that aircraft. This discrepancy was responsible for some, but not all of the difference. Inspection of the raw data indicates that four of the eight pilots took an abnormally long time to start the engines on their first repetition with EMADS (forty to seventy seconds above the mean). Such differences did not occur during the second repetition and thus, very little difference exists between EMADS and conventional instruments. The large discrepancy for these four pilots may have been due to learning effects.

Because EMADS is capable of monitoring all engine parameters during each flight phase (including startup), it should be feasible to provide cues based on EGT, N_1,or any combination of engine parameters that will expedite engine starting.

Preflight: Fault Monitoring

During four trials (two each for EMADS and conventional instruments), either a hot or a hung start was introduced in one of the engines during the start process. Pilots were instructed to take appropriate corrective action as soon as the problem became evident.

Approximately seventeen seconds elapsed from the time the faults were initiated in the system software until rate changes were sensed by both

engine displays. All data were transformed (seventeen second subtraction) to yield a more representative set of detection and response times. A two way analysis of variance with repeated measures was performed on the results which are illustrated in Figures 9 and 10. In terms of detection and response time, performance was better in correcting the hot start condition when EMADS was used while conventional instruments produced the best performance on the hung start condition. The response time data provide a good illustration of the system monitoring processes used by the pilots and by EMADS. For this study, a hung start was defined as a twenty-five second interval after the fuel flow was initiated where the EGT remained at or below two hundred degrees Fahrenheit (200^{o} F.). A hot start, on the other hand, was when the EGT was greater than seven hundred and fifty degrees Fahrenheit (750^{o}F.) for forty seconds or the change in the EGT was greater than twenty-five degrees per second at twenty seconds after the fuel flow was initiated. Obviously, a hung start was much easier to identify than a hot start because it represented a discrete event where no rate-of-change calculations were required. In fact, the pilots actually performed better with conventional instruments because they realized a hung start was imminent slightly before the twenty-five seconds called out in the fault definition while, with EMADS, most pilots waited for the cue on the display screen which was not presented until twenty-five seconds after fuel flow initiation. This represents an area where software modifications could provide a more expedient cue when this fault occurs. The response time data for the hot start provides an illustration of the primary strength of EMADS: the ability to monitor rate changes and provide status information on a real-time basis. This is evidenced by the improved performance resulting from the use of EMADS during the hot start condition. It should also be noted that the performance differences between the two display systems were not statistically significant.

Takeoff: Normal Operations

The following parameters were recorded for analysis during the takeoff roll:

FIGURE 9. PREFLIGHT: FAULT MONITORING
DETECTION TIME

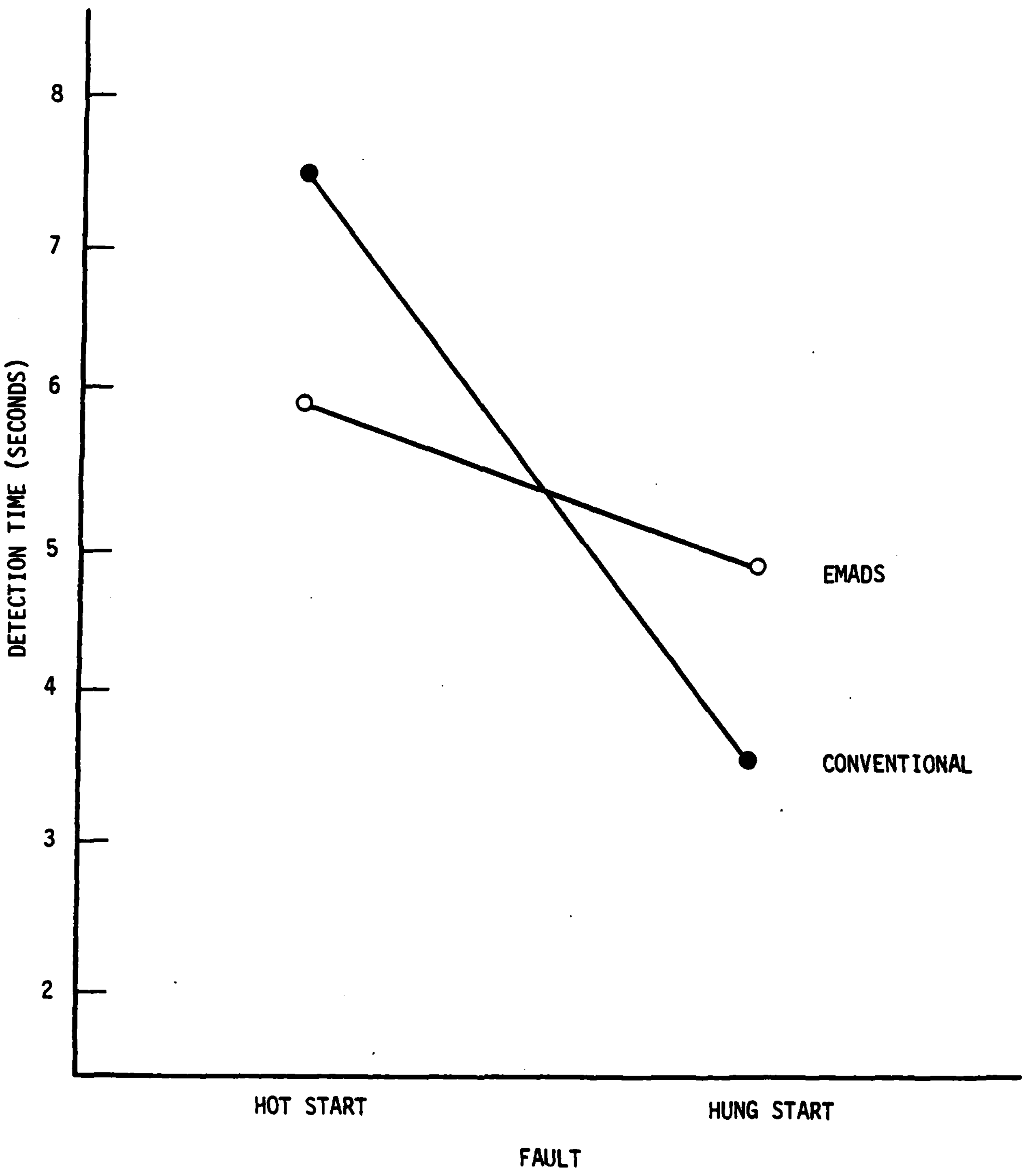
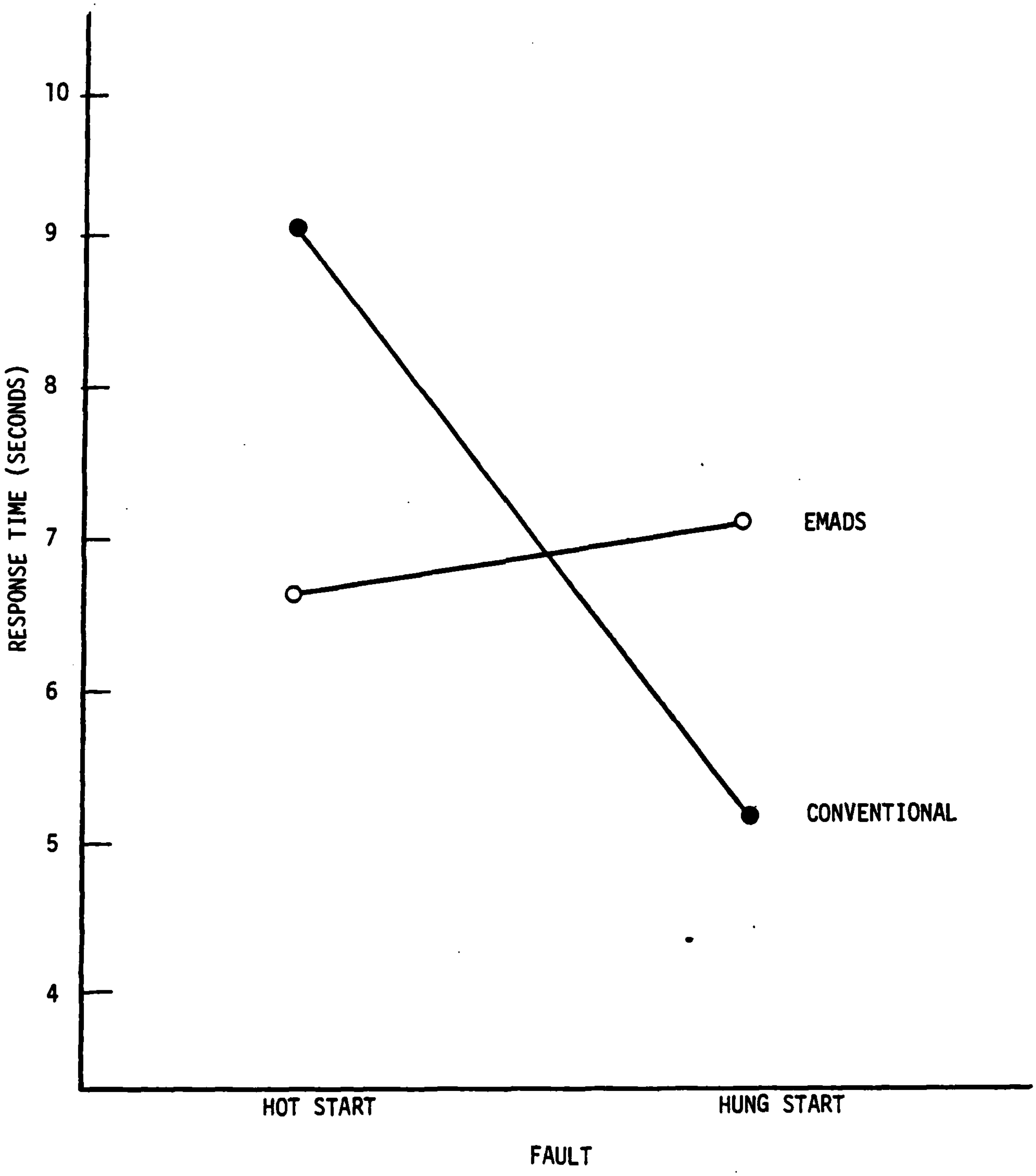


FIGURE 10. PREFLIGHT: FAULT MONITORING RESPONSE TIME



1. Mean N_1 setting at 80 knots
2. Mean N_1 setting at V_1
3. Throttle adjustment between 80 knots and V_1

At 80 knots and at V_1, the N_1 value was measured and recorded as a means to evaluate throttle setting accuracy. Standard DC-10 operating procedures state that takeoff power should be set by 80 knots and that both of the pilots hands should be on the control wheel by V_1 (the velocity after which the takeoff cannot be safely aborted).

An analysis of variance was performed on both sets of data, the results of which are illustrated in Figures 11A and 11B. As can be seen in these figures, the pilots consistently set power more accurately with EMADS, although these differences in accuracy were not statistically significant. With conventional instruments, the pilots tended to underboost the engines more so than with EMADS. This may have been due to the fact that a positive indication of within-limit power setting was provided on the EMADS display. It may be that the absence of such an indication on the conventional dials caused the pilots to exercise additional caution to avoid overboosting the engines.

An analysis of variance was also performed on the difference between the N_1 value at V_1 and 80 knots. This provided a measure of the amount of throttle adjustment being made after 80 knots. As can be seen in Figure 12, more throttle adjustment was made after 80 knots with EMADS than conventional instruments. This difference however, was not statistically significant.

<u>Takeoff: Fault Monitoring</u>

Shortly after takeoff for eight of the sixteen trials (four each for EMADS and conventional instruments), either an N_1 or EGT exceedance was presented. Pilots were instructed to correct the problem quickly and accurately while maintaining safe and accurate control of the aircraft.

An analysis of variance was performed on the results which are illustrated in Figures 13 and 14. In terms of detection and response times, performance was significantly better when EMADS was employed ($P<.05$). This was primarily due to the fact that, with EMADS, a

FIGURE 11A. TAKEOFF: NORMAL OPERATIONS
THROTTLE SETTING ACCURACY AT 80 KNOTS

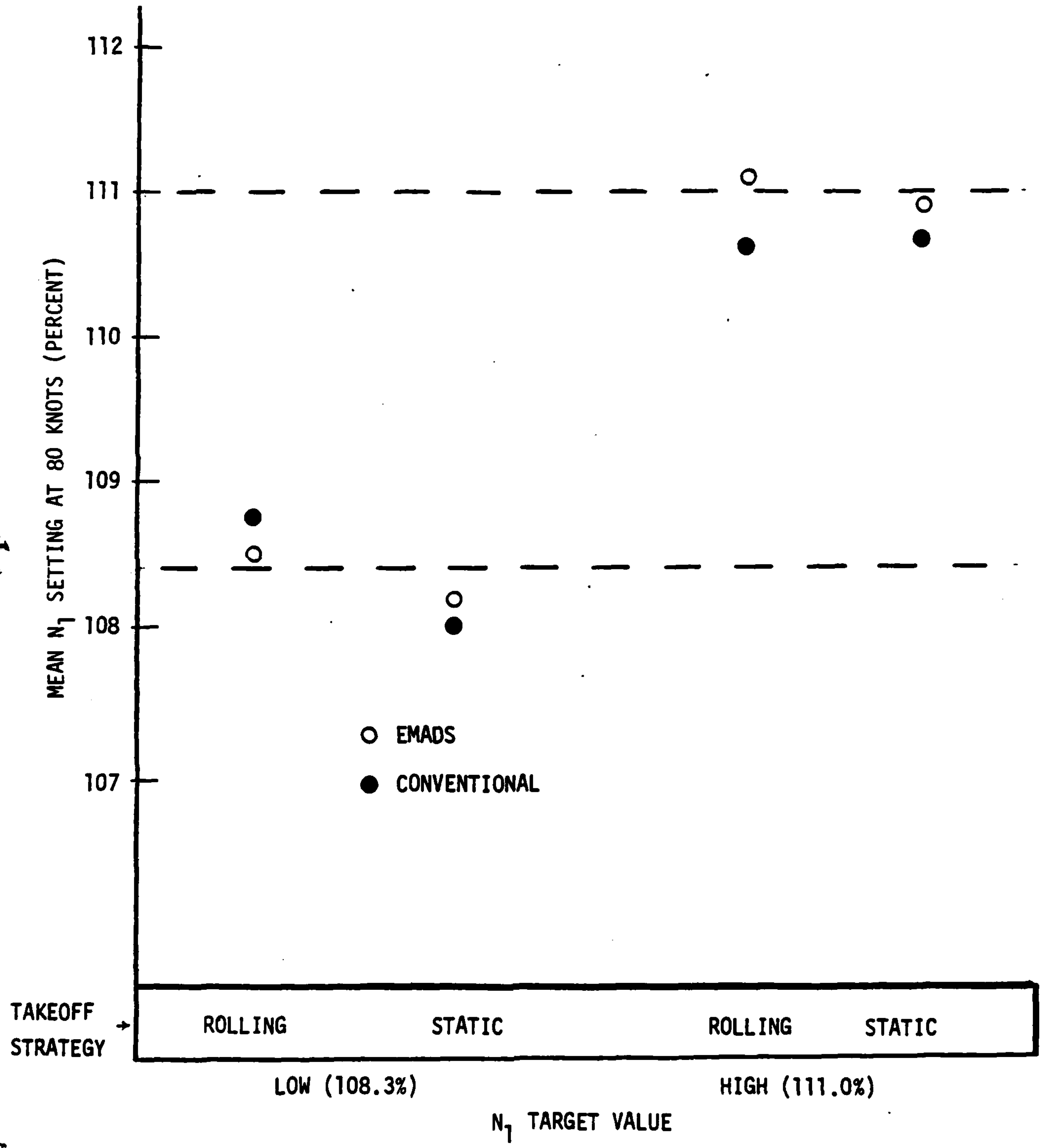


FIGURE 11B. TAKEOFF: NORMAL OPERATIONS
THROTTLE SETTING ACCURACY AT V_1

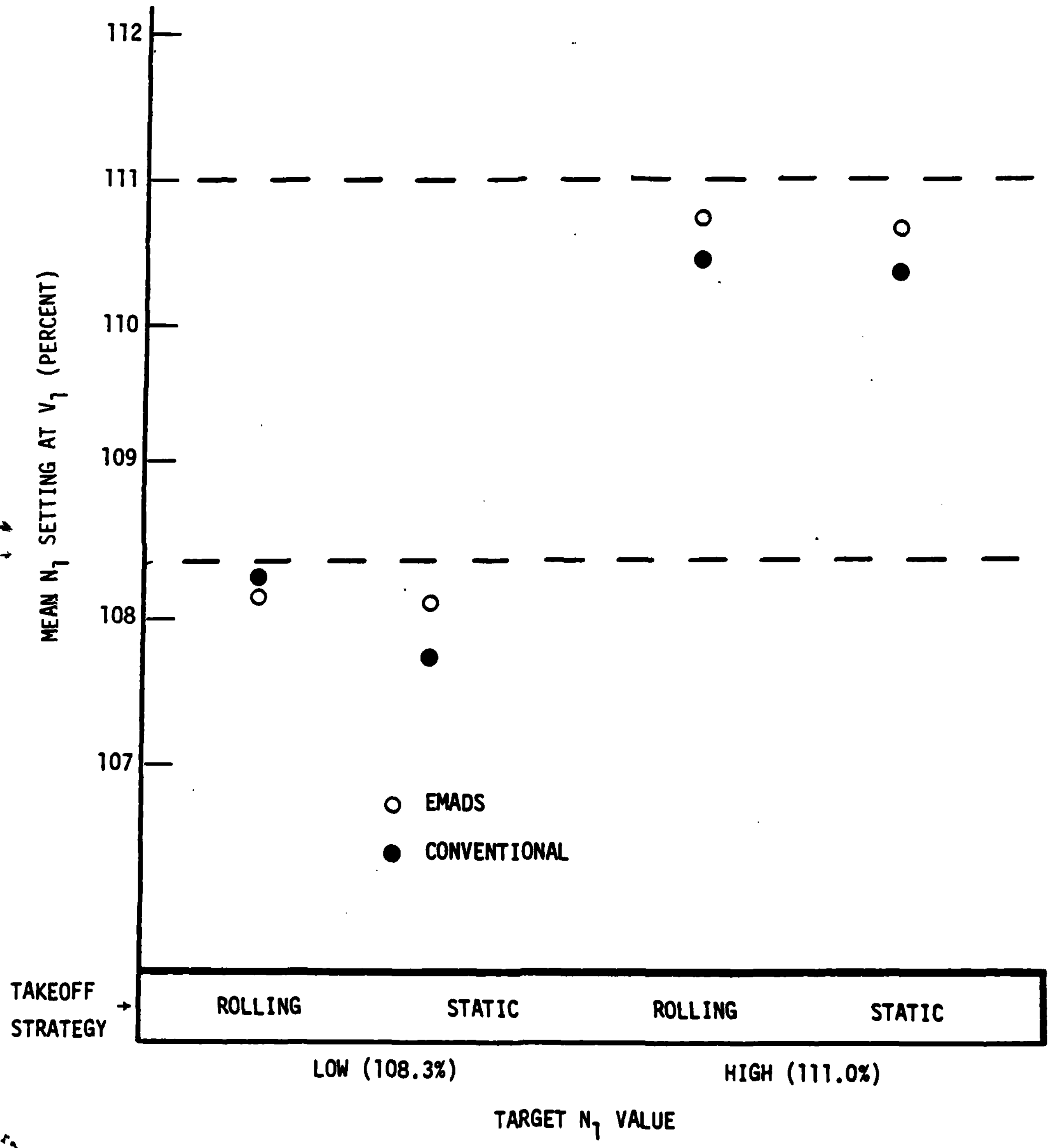


FIGURE 12. TAKEOFF: NORMAL OPERATIONS
THROTTLE ADJUSTMENTS BETWEEN 80 KNOTS AND V_1.

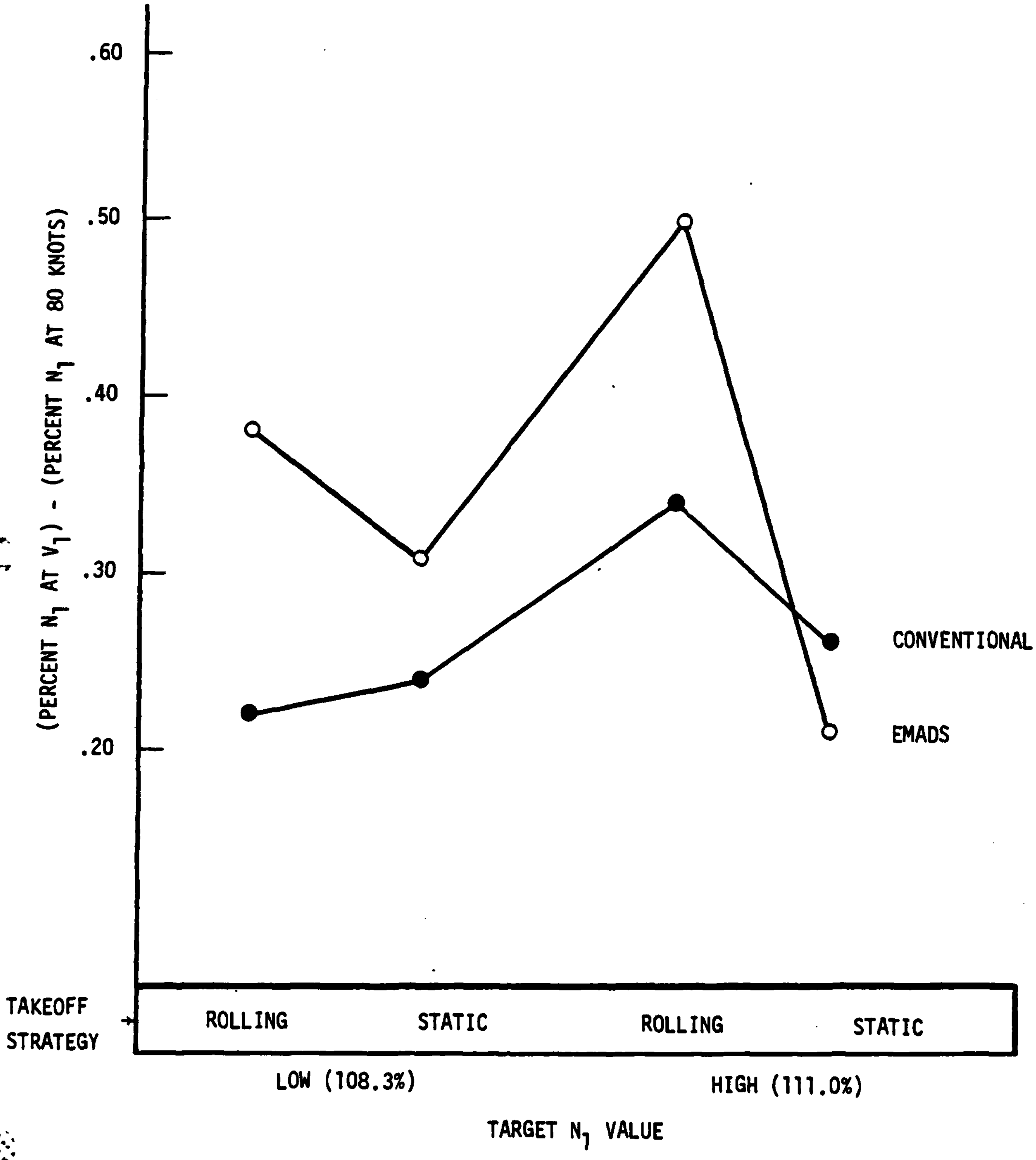


FIGURE 13. TAKEOFF: FAULT MONITORING DETECTION TIME

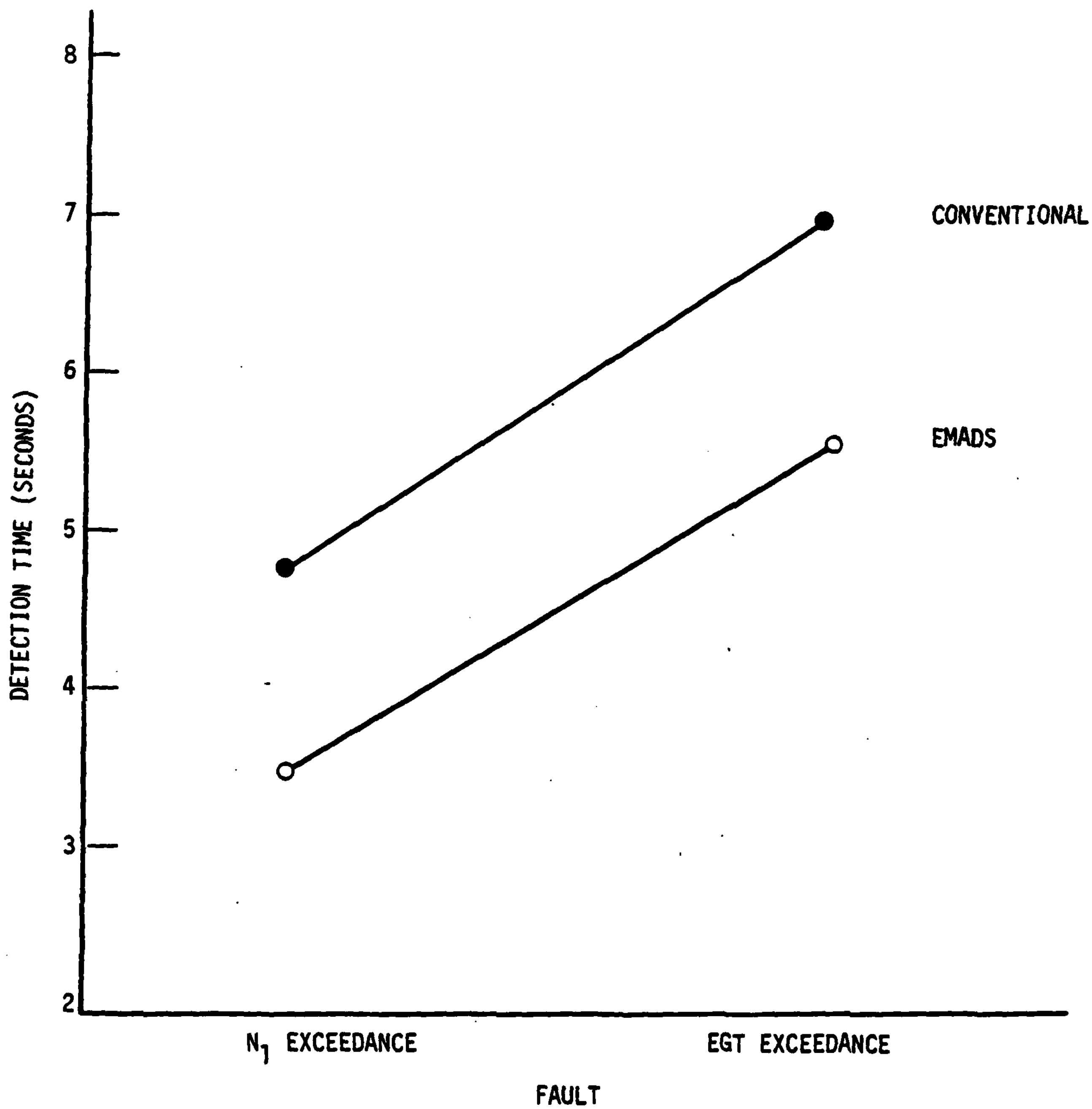
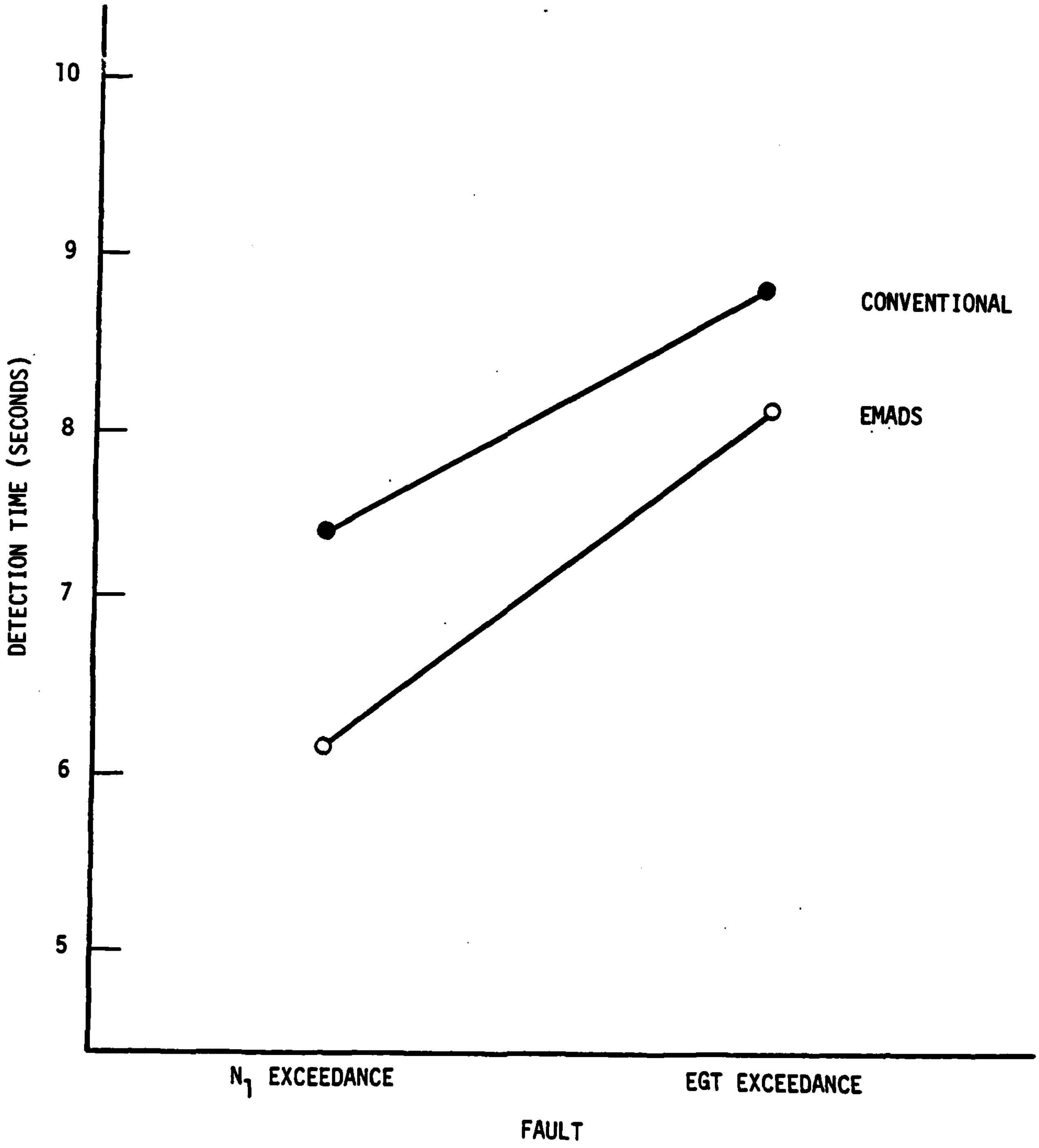


FIGURE 14. TAKEOFF: FAULT MONITORING RESPONSE TIME



positive indication (flashing engine legend) was provided for both faults while, with conventional instruments, a positive indication was provided only for the EGT exceedance. The indication provided by EMADS was significantly more obtrusive than that provided by conventional instruments. Given the fact that both displays were located outside the pilots primary field of vision, this capability provided a distinct advantage to EMADS which is illustrated in Figures 13 and 14. It is likely that these performance differences would shrink significantly if both engine monitoring systems were tied into the master caution system.

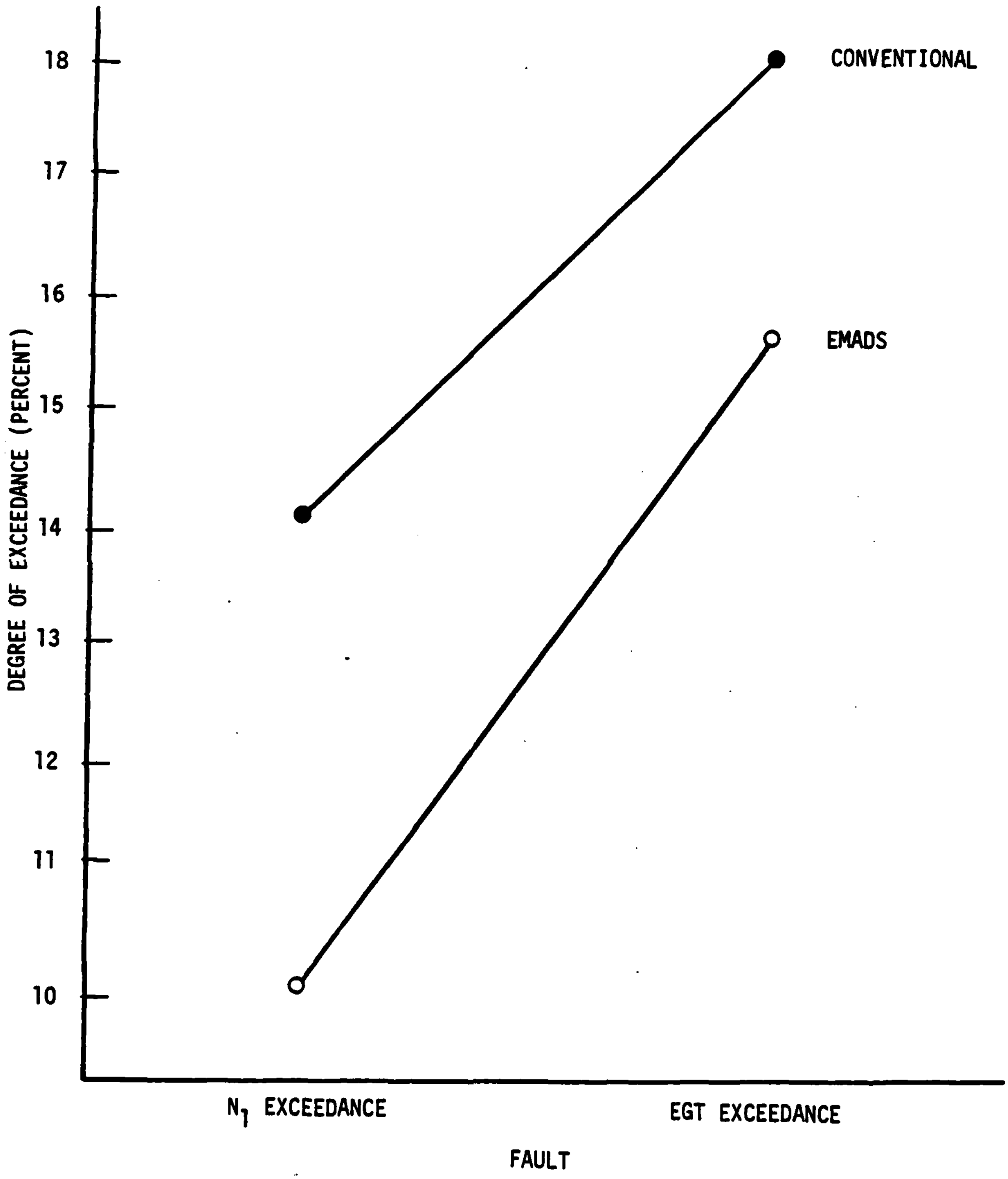
An analysis was also performed on the degree (measured in percent) of N_1 and EGT exceedance that occured during the fault correction process. This measurement represented the value of the N_1 or EGT parameter at the point where corrective action was initiated, less the normal value. When viewed along with the response time measurements, a clear picture of potential engine damage emerges in terms of both degree and duration of the exceedance.

Analyses of variance were performed on the N_1 and EGT exceedance values for both EMADS and conventional instruments, the results of which are illustrated in Figure 15. The use of EMADS resulted in a statistically significant reduction in exceedance values for the N_1 parameter ($p<.01$). Although a lower level of exceedance was also found with the EGT faults when EMADS was employed, this difference was not statistically significant. A high correlation can be seen when a comparison is made between these results and those obtained in the takeoff fault monitoring analysis, where response time differences were generally more pronounced for the N_1 exceedances.

Inflight: Fault Monitoring

During eight of the sixteen trials (four each for EMADS and conventional instruments), either an engine flameout or EGT exceedance was initiated at a predetermined time after the aircraft passed 3,000 feet. Again, pilots were instructed to take corrective action while maintaining safe and accurate control of the aircraft.

FIGURE 15. TAKEOFF: FAULT MONITORING
DEGREE OF N_1 AND EGT EXCEEDANCE



An analysis of variance performed on the results revealed no statistically significant differences in terms of detection and response times. Depending on the fault involved, performance was slightly better with EMADS or conventional instruments, as illustrated in Figures 16 and 17. The relatively low workload during this flight segment could account for the lack of statistical significance in the results. It is believed that the attention getting and performance benefits associated with EMADS will generally increase with the level of visual task loading.

An analysis of variance was also performed on the degree of EGT exceedance and, as with the detection and response time data, no statistically significant differences were found.

Takeoff and Inflight: Heading Deviation

During each trial, heading deviation was measured and recorded for ten second intervals during the takeoff and inflight segments. When faults were introduced, the ten second intervals were initiated concurrently with the onset of the fault. When no faults were introduced, the time interval was initiated at a predetermined time that corresponded to one of the fault onset times. By measuring flight task performance during periods where fault detection and correction was occurring, it was possible to assess the distracting effects that the alerting process imposed on the flight task.

Due to a software computational problem, RMS values for heading devation were not available for analysis. Instead, an analyses of variance was performed on the average deviations for the raw data. This analysis revealed no statistically significant differences between EMADS and conventional instruments.

Debriefing Questionnaire

Immediately following the test session, each pilot was asked to complete a debriefing questionnaire which addressed the relative merits of EMADS and conventional instruments. The results of this questionnaire are shown in Figure 18 and Table 5. Overall, the pilots felt that EMADS was superior in terms of system monitoring, fault monitoring, workload

FIGURE 16. INFLIGHT: FAULT MONITORING DETECTION TIME

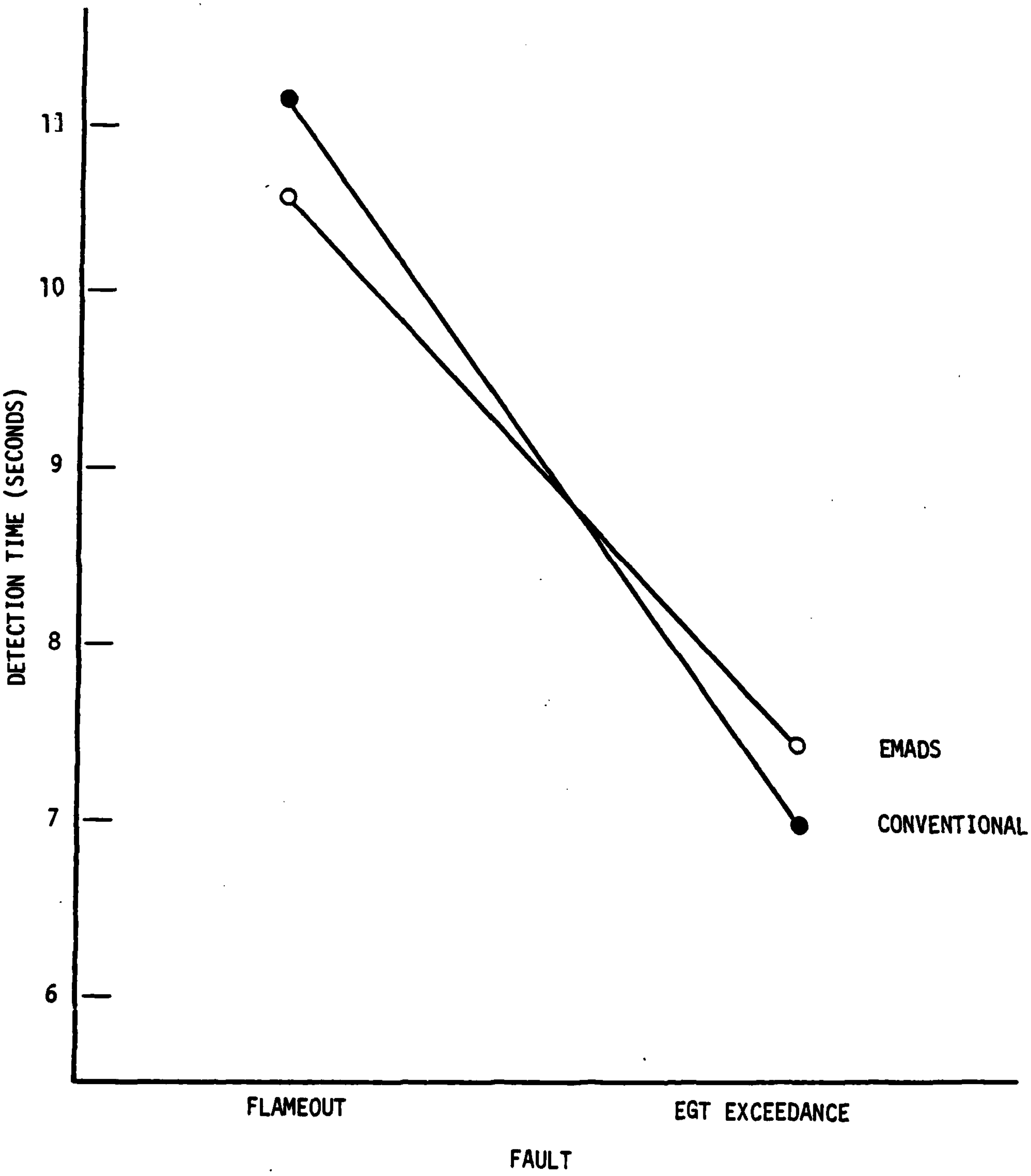
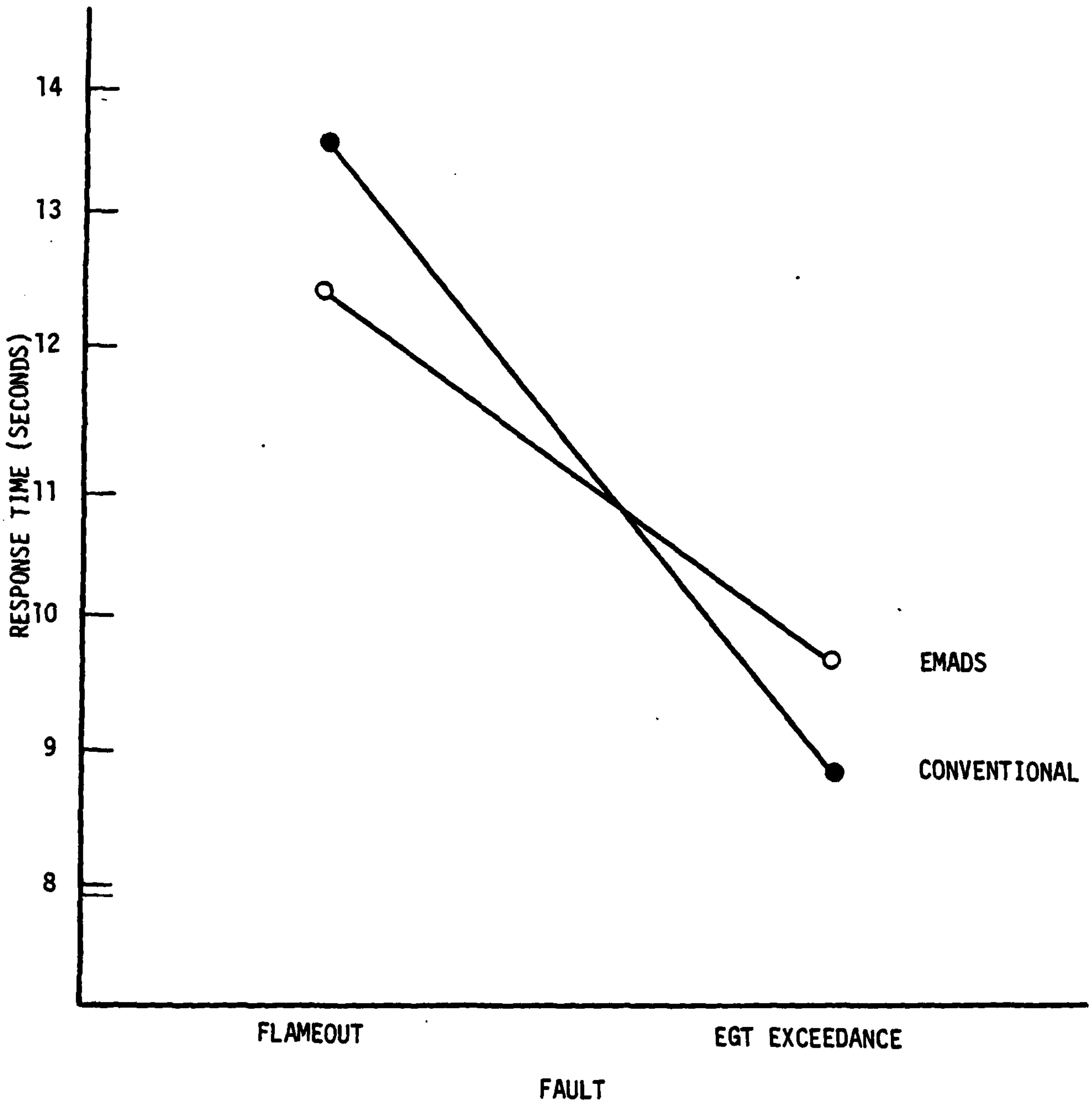


FIGURE 17. INFLIGHT: FAULT MONITORING RESPONSE TIME



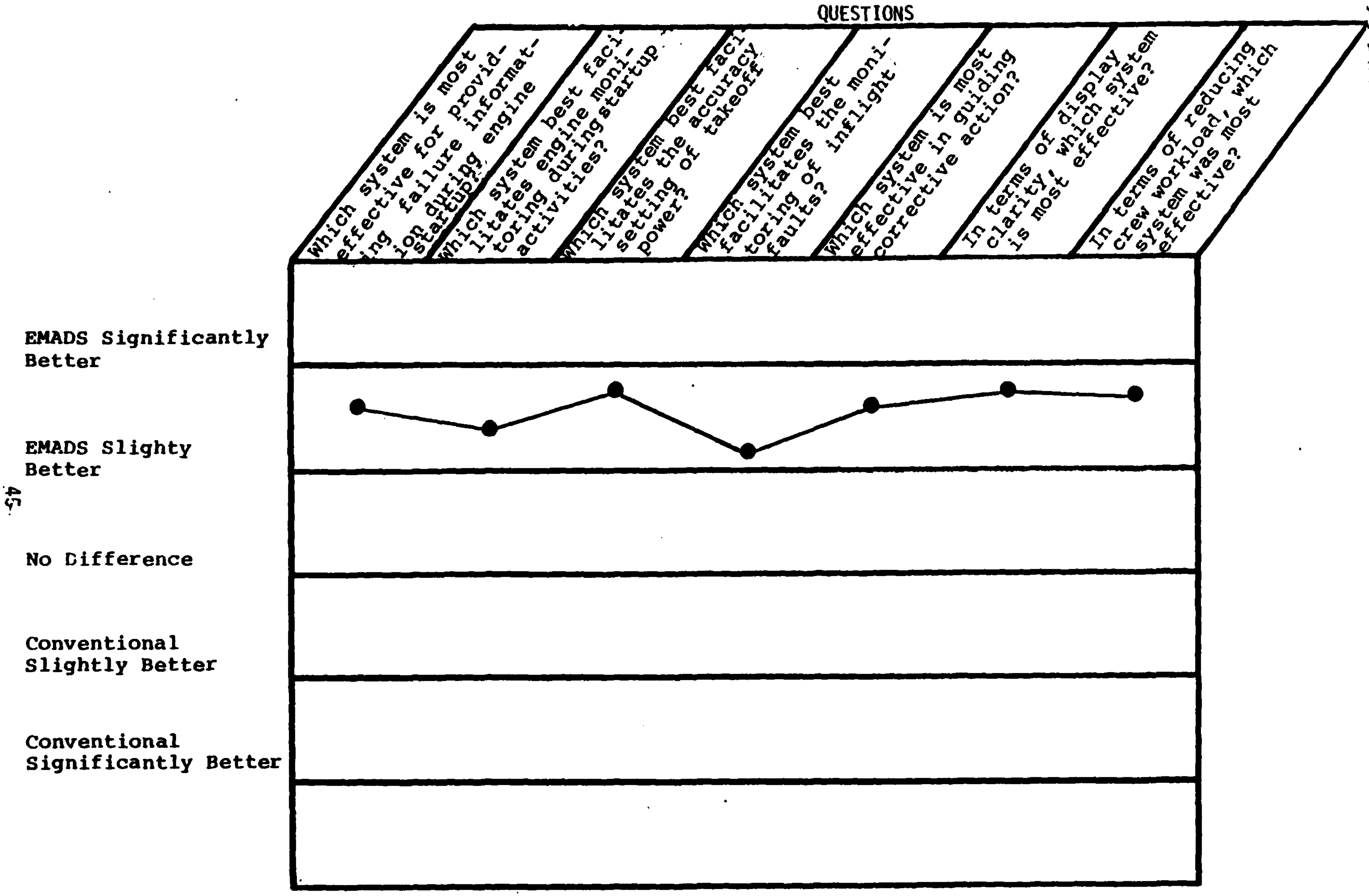


Figure 18. Questionnaire Results - Mean Pilot Ratings

TABLE 5

QUESTIONNAIRE RESULTS	
DO YOU FORESEE ANY PROBLEMS IN TRAINING PILOTS EXPERIENCED WITH CONVENTIONAL INSTRUMENTS IN THE USE OF EMADS?	
YES	0
NO	9
NOT SURE	0
DO YOU FORESEE ANY PROBLEMS IN TRAINING PILOTS TO USE CONVENTIONAL INSTRUMENTS IF THEIR ONLY PREVIOUS EXPERIENCE IS WITH EMADS?	
YES	2
NO	5
NOT SURE	1
OVERALL, WHICH SYSTEM WOULD YOU PREFER IN FUTURE AIRCRAFT?	
EMADS	9
CONVENTIONAL	0
ANOTHER TYPE OF DISPLAY	0

reduction, and power setting accuracy. A majority could foresee no transfer of training problems for pilots transitioning between EMADS and conventional instruments. Overall, EMADS was the clear preference of all pilots questioned. An additional summary of the questionnaire results and comments can be found in Appendix E.

The pilots provided a number of useful comments, both during the test session and as part of the debriefing questionnaire. A summary of the comments made most frequently can be seen in Table 6. In general, they felt that the EMADS display was easier to read and incorporate into their scan pattern; they also liked the obtrusive attention getting cues and the automated checklists. A number of the pilots stated that the effectiveness of EMADS could be enhanced with the application of color.

TABLE 6

SUMMARY OF PILOT COMMENTS

COMMENTS	NUMBER OF PILOTS
EMADS WAS EASIER TO INCORPORATE INTO THE SCAN PATTERN AND EASIER TO MONITOR FOR ABNORMALITIES	8
EMADS WAS MORE ATTENTION DEMANDING DURING FAULT CONDITIONS	5
EMADS WAS EASIER TO READ	3
EMADS WAS SIMPLIER IN TERMS OF DISPLAY ORGANIZATION	3
THE USE OF COLOR WOULD INCREASE THE EFFECTIVENESS OF EMADS	3
EMADS PROVIDED A USEFUL CHECKLIST CAPABILITY	2

DISCUSSION

A number of efforts have been undertaken as part of a program to develop and improve the EMADS concept involving personnel from Douglas Aircraft, General Electric, and a large number of representatives from various airlines, manufacturers, and regulatory agencies. The major thrust of each of these efforts was to develop and subjectively assess the effectiveness of EMADS relative to both stated design objectives and the current capability provided by conventional engine instruments. Each of these efforts has produced results that reflect quite favorably on EMADS. After obtaining these results, it was determined that a study designed to generate objective performance data should be conducted to validate the EMADS concept relative to current engine control and monitoring capabilities.

This study involved a series of experiments designed to measure pilot performance under a variety of conditions using EMADS and conventional instruments. It was hypothesized that EMADS would be as good as or better than conventional instruments in terms of performance on the flight and fault correction tasks for each experiment. Each experiment provided a unique body of data that was used to assess the relative utility of the two display systems; in addition, subjective data was collected by way of a debriefing questionnaire as well as through experimenter-pilot interaction during the test session.

For a majority of the experiments, the data validated the EMADS concept in terms of pilot performance when compared to conventional instruments. This was the case for all fault monitoring tasks as well as the subjective input provided by the pilots. The only exception was during the normal-operations portion of the preflight activities where significantly less time was required to start all engines when conventional instruments were used. This time, reduction was only evident during the first repetition while no significant performance differences were found on the second iteration. This suggests that inadequate training with EMADS may have been the source of this difference. It was also noted that software modifications to EMADS could provide more expedient action cures based on any appropriate combination of engine parameters. Based on these considerations, the

performance differences described in the results section do not represent an area of special concern.

Analysis of the preflight fault monitoring data revealed comparable performance levels for the two display systems. The small performance differences that were found did not consistently favor either system. This experiment illuminated one of the potential advantages of EMADS which is the capability to automatically monitor system abnormalities that occur as a function of parameter rate changes. EMADS resulted in noticeably better performance with the hot start than with the hung start; it is believed that this difference was due to the fact that early identification of a hot start condition requires more complex computational activity. High speed computers can carry out this type of activity significantly faster and more accurately than humans and thus, a potential operational advantage of EMADS was exposed.

During the takeoff roll, no significant performance differences were found, although power setting was slightly more accurate when EMADS was used. EMADS provided a positive indication (brightened chevron) when the N_1 value was within $\pm$ one percent of the command value. It is believed that by reducing these limits to $\pm$ one half of one percent, a significant improvement in power setting accuracy could be realized with EMADS.

The use of EMADS resulted in significantly better performance on the fault monitoring task that occured after takeoff. Performance was better in terms of response time, detection time, and percent of exceedance on both the N_1 and EGT parameters. The obtrusive indications provided by EMADS for abnormal conditions were largely responsible for these performance differences.

Use of the two display types resulted in comparable performance levels for fault monitoring during the inflight segment. No significant performance differences were found in the measurements of response time, detection time, or percent of EGT exceedance. It is believed that the relatively low level of visual task loading was primarily responsible for the lack of significant results. The pilots were able to include the engine display in thier scan pattern somewhat more frequently than

would normally be the case. Given a higher level of visual workload, it is likely that the use of EMADS would result in measurably better performance. The low level of visual workload also resulted in a minimal performance difference between the two display types in terms of heading deviation. The lack of significance in the fault monitoring and flight task performance can be used to highlight some of the more significant problems encountered in attempting to conduct a sophisticated simulation exercise. One of the main drawbacks of simulating abnormal operations is that subjects are exposed to an unusually high number of failure conditions in a relatively short period of time. This tends to encourage or produce a mental "set" where subjects devote more attention to system monitoring than would be the case in an actual operational environment. This generally results in smaller performance differences between experimental treatment conditions. In addition the time constraints associated with simulator scheduling do not allow much time for test design revision to refine the experimental paradigm. In one case, last minute changes were required because of simulator malfunctions that reduced the workload level during the inflight segment of the study. Because it is impossible to anticipate the specific effects of such changes, an assessment of the potential impact must be made on a case-by-case basis and, in most instances, tradeoffs are required if the study is to continue. Finally, the cost required to conduct a full mission simulation is generally higher than that which can reasonably be absorbed by an internal research and development budget. Because of this, some degree of realism must be sacrificed in order to remain within the predetermined financial limits. This serves to reduce the face validity of the simulation environment and restrict the level to which results can be generalized to the "real world".

The subjective data produced results similiar to those of previous efforts. The pilots showed a clear preference for EMADS in each area addressed by the questionnaire. They also felt that transfer of training problems would be minimal, regardless of which system was originally learned. This was encouraging because one of the major obstacles to implementing advanced systems is the resistance to change shown by operational personnel who have spent a number of years becoming comfortable with a particular system.

CONCLUSIONS AND RECOMMENDATIONS

Since both the subjective and objective data reflect positively on EMADS, it seems safe to conclude that this system can provide a potentially useful supplement to advanced flight deck design. It should be noted, however, that a number of issues will need to be addressed in order to refine the EMADS concept prior to actual implementation.

There are several human factors considerations to be made that should ultimately improve both performance and user acceptance. The first involves the checklist capability, particularly as it relates to abnormal operations. In situations where attention is to be drawn to a particular situation or corrective action, the cue that leads the eye to that information should be the most obtrusive item on the display. When that information has been conveyed or the appropriate action taken, the next piece of information should be emphasized accordingly.

For the most part, checklist items for fault conditions are performed serially. The present configuration of EMADS presents checklist items as a list, with the message on top to be performed first, the second message to be performed next, and so on. A number of different methods can be employed to minimize operator confusion in performing checklist functions. The simplest method involves displaying only one item at a time and when that task has been completed, remove it and display the next item. When all tasks have been completed, a positive indication to that effect should be provided (e.g. ENGINE SHUTDOWN CHECKLIST COMPLETE). Other methods include color coding, the use of asterisks(*) or checks (✓) after completed items (i.e. prestart checklist), manual cancellation of completed items (tasks that cannot be computer monitored), and flashing indicators adjacent to items not yet completed.

A careful analysis should be made to determine the most appropriate format for procedural checklists because delayed action could result in unnecessary engine damage.

The use of color represents an area where significant improvements can be made to the EMADS display format, clarity and readability. Earlier surveys indicated that pilot acceptance of color coding would be high

and a number of participants in this study suggested that the effectiveness of EMADS could be increased if color were appropriately applied.

As mentioned in a previous section, a number of the pilots who participated stated that the acceptable N_1 command limits ($\pm$ one percent of the command value) were excessive and that they should be reduced to one half on one percent. These limits should be investigated relative to optimum engine operating conditions and adjusted accordingly.

Another area of concern involves the general arrangement of engine parameter information on the display screen. Conventional instrument configurations place the N_1 dials at the top of the group for each engine (with EGT, N_2, and fuel flow below). With EMADS, the N_1 information is always at the bottom of the group, regardless of whether the presentation is analog or digital. In developing an optimum display format, care should be taken to avoid unnecessary transfer of training problems. A number of unnecessary format changes can be avoided if the system designer is aware of the possibility of such problems.

Finally, if EMADS is to be used effectively in an advanced cockpit, it must be carefully integrated with other information displays. A number of display technologies are available and under consideration for advanced flight deck application. Some knowledge should be gained in the areas of compatability requirements, multifunction capability, backup display requirements, and panel space availability. Each of these areas will require investigation to determine the optimum control-display arrangement.

It is recommended that additional research be done to resolve these issues as well as those that are exposed in the interim. The ultimate goal is to provide an efficient, reliable engine monitoring and display system that allows the crew to effectively deal with normal as well as emergency conditions. Reliability is extremely important because the increased automation inherent in this type of system requires a high degree of pilot confidence in the system's ability to provide accurate information. In addition, the novelty of the EMADS design relative to

conventional instruments may serve to reduce acceptance by operational personnel who are not accustomed to evaluating advanced concepts. By addressing each of the aforementioned issues and simplifying the display design where possible, this reluctance should be reduced.

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2. Society of Automative Engineers. Aerospace Recommended Practice: Flight Deck Visual, Audible and Tactile Signals (Draft ARP-450D), Society of Automative Engineers, Inc.; New York, April, 1980.

APPENDIX A

COUNTERBALANCING TABLE

RVR	SUBJECT	CELL NUMBER															
2400	1	1	2	8	3	7	4	6	5	9	10	16	11	15	12	14	13
	2	2	3	1	4	8	5	7	6	10	11	9	12	16	13	15	14
	3	3	4	2	5	1	6	8	7	11	12	10	13	9	14	16	15
	4	4	5	3	6	2	7	1	8	12	13	11	14	10	15	9	16
700	5	13	14	12	15	11	16	10	9	5	6	4	7	3	8	2	1
	6	14	15	13	16	12	9	11	10	6	7	5	8	4	1	3	2
	7	15	16	14	9	13	10	12	11	7	8	6	1	5	2	4	3
	8	16	9	15	10	14	11	13	12	8	1	7	2	6	3	5	4
Run No.:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

COMPARATIVE EVALUATION:
EMADS - CONVENTIONAL INSTRUMENTS
COUNTERBALANCING TABLE

APPENDIX B

BRIEFING OUTLINE

BRIEFING GUIDE

EMADS COMPARATIVE EVALUATION

Questions on reading

1. Test Overview

   a. Comparative evaluation: EMADS vs. conventional

   b. Engine display functions only

   c. Test facility

      (1) Developmental simulator (not training)

      (2) Relatively incomplete cockpit

      (3) Representative 3-engine wide-body transport (not necessarily DC-10)

   d. Test procedure

      (1) Series of partial flight profiles: take-off and climb-out

      (2) Fixed-base simulation only

      (3) Terrain model visual system

      (4) Test sequence (EMADS-conventional)

      (5) Test conditions will vary from trial to trial

         (a) Take-off strategy (rolling/static)

         (b) N_1 limit value (high/low)

      (6) On some trials, simulated engine or system faults will be introduced

         (a) Hung start

         (b) Hot start

         (c) N_1 or EGT exceedance

         (d) Flameout

      (7) Data recorded

         (a) Throttle setting accuracy during take-off

         (b) Accuracy of aircraft control

         (c) Time required to detect faults and initiate corrective action

         (d) Safe and accurate control of aircraft

      (8) Subjective assessment

         (a) Comments during test trials

         (b) Post-test questionnaire/debriefing

2. EMADS Familiarization (Video Tape)

   a. Overview of functional capabilities of EMADS

   b. During the test only basic engine display functions will be evaluated

   c. Some format details on the video tape are not current

   d. Feel free to ask questions

   e. A detailed description of each of the modes used in the test will be provided in the cockpit

EMADS-CONVENTIONAL INSTRUMENTS

COCKPIT BRIEFING, PRACTICE AND TEST RUN PROCEDURE

1. Describe cockpit configuration (reiterate).
   a. Developmental simulator (used as DC-9, YC-15 and DC-10)
   b. For this study, represents 3-engine wide-body aircraft
   c. Not necessarily a DC-10

1A. Describe taping system and ask permission to tape.

2. Review active displays and controls.
   a. Control wheel steering
   b. Trim switches
   c. Fault detection switch (will describe later)
   d. ADI, HSD, altimeter, VSI, IAS
   e. Vertical speed wheel and control
   f. Master caution light
   g. Overhead annunciator lights (cue lights)
   h. APU isolation value
   i. Override/airstart switch
   j. Landing gear lever
   k. Flap/slat controls
   l. Stabilizer position indicator
   m. Spoilers (not used in study)
   n. Parking brake
   o. EMADS control panel (EMADS portion only)
   p. Engine instruments (EMADS or conventional)

3. Simulator idiosyncracies.
   a. Rudder pedal steering only
   b. FMA similar to but not identical to that on a DC-10
   c. Throttle response similar to but not same as DC-10
   d. Overspeed barber pole not appropriate for present simulation configuration-no overspeed warning will occur

4. [FOR EMADS ONLY] Review function modes.
   a. Start cassette tape by cueing ground station
   b. Review keyboard
   c. Bring up pre-start checklist and complete
   d. Start one engine to illustrate
      (1) Digital and analog readout of engine parameters
      (2) Cues for pilot activity
      (3) Clock

4. (Cont'd)

   e. T/O mode to illustrate

      (1) Automatic and manual N_1 value setting

      (2) Throttle movement and chevron brightening

      (3) Allow pilot to set static power 1-2 times

      (4) Illustrate chevron dimming both above and below command value

      (5) Illustrate exceedance

   f. Climb mode to illustrate

      (1) Change to N_1 values only

      (2) Climb thrust reduction to 103.3% N_1

      (3) All engine instruments capability

5. Review visual scene to be used for all flights.

   a. 2400 feet RVR and 220 foot cloud base

      OR

      700 feet RVR and 70 foot cloud base

6. Review flight plan.

   a. Specific T/O strategy (rolling/static) and N_1 command value for each flight

   b. Review each activity on flight scenario description

7. Co-pilot activities.

   a. Call out 80 kts and V speeds

   b. Gear up on pilot command

   c. Cue pilot as to flight management activities

      (1) Advise of climb thrust change at 2000 feet

      (2) Adjust vertical speed wheel at 3000 feet on pilot command

      (3) Flap and slat retract at appropriate speeds on pilot command

      (4) [FOR CONVENTIONAL ONLY] Adjust N_1 command values for climb to 103.3% N_1

8. Practice take-offs and climb-outs (2)

   a. 1 static and 1 rolling (static first)

   b. [FOR CONVENTIONAL ONLY] Complete pre-start checklist per reference sheet

   c. Start engines first time only (Don't move fuel lever until cued)

   d. Complete T/O checklist

   e. Advise pilots

      (1) Should have T/O power set by 80 kts

      (2) Shouldn't touch throttles after V_1

9. Review and define each fault and action to be taken.

	Fault	Definition	Corrective Action
a.	Hung Start (no ign)	EGT $<200_0$ after 25 sec	Detect, fuel lever off, after 30 sec., pull st. switch, re-start engine.
b.	Hot Start	EGT $>750_0$ for 40 sec or EGT $\geq 25_0$/sec at 20 sec after fuel lever on	Detect, fuel lever off, motor 30 sec, pull st. switch, re-start engine.
c.	N_1 or EGT Exceedance	$N_1 > 116\%\ N_1$ EGT $>875^{o}$	Detect, pull throttle quickly, back almost to idle and then back to normal position.
d.	Flameout	One N_1 $>11\%$ less than other N_1 with at least one N_1 at 70%	Detect, push override/ airstart switch to on position.
e.	Auxiliary Faults	Master caution light on and overhead annunciator light on (1) Select flap limit override (2) Upper yaw damp inop (3) Pneu temp high (4) R windshield anti-ice inop (Demonstrate by pushing test switch on overhead cue light panel.)	Detect, depress overhead annunciator switch.

f. Auxiliary faults are configured on cue light panel for this study and not representative of any cockpit.

g. Call out "detect" when detect switch is depressed and push it with force to ensure registration. (Call out is required to verify action because this is a highly nonstandard activity.)

h. Advise pilots to depress detect switch as soon as they sense a problem, regardless of whether or not they know what it is.

i. Be sure to push fuel levers completely off.

j. [FOR CONVENTIONAL ONLY] Point out EGT exceedance cue light.

10. Two practice runs (#2 and #3) with cues
    a. Walk through each run with pilot and
        (1) Advise as to what faults will occur and when
        (2) Advise as to the appropriate corrective action

11. Two practice runs (#2 and #3) without cues

12. Eight test runs

13. System changeover

14. Briefing for second configuration
    a. If conventional
        (1) Refer to items
            -2P
            -4A, D, E, F
            -8A, B, C, D
            -10
            -11

        (2) Also point out EGT exceedance cue light
    b. If EMADS
        (1) Refer to items
            -2O, P
            -4A, B, C, D, E, F
            -8A, C, D
            -10
            -11

15. Test runs
16. Debriefing

APPENDIX C

DEBRIEFING QUESTIONNAIRE

EMADS-CONVENTIONAL ENGINE INSTRUMENTS

DEBRIEFING QUESTIONNAIRE

1. Which system provides the best overall status of engine health?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ______________________________

2. Which system is most effective for providing failure information during engine start-up?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ______________________________

3. Which system best facilitates engine monitoring during start-up activities?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ______________________________

4. Which system has the best performance assessment capabilities?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ____

____

____

5. Which system best facilitates the accurate setting of take-off power?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ____

____

____

6. Which system best facilitates the monitoring of in-flight faults?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ____

____

____

7. Which system is most effective in guiding corrective action?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ____

____

____

8. In terms of display clarity, which system is most effective?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Why? ____

____

____

9. Do you forsee any problems in training pilots experienced with conventional instruments in the use of EMADS:

Yes ____________ No ____________ Not Sure ____________

If yes, explain:

____

____

____

____

10. Do you foresee any problems in training pilots to use conventional instruments if their only previous experience is with EMADS?

Yes ______________ No ______________ Not Sure ______________

If yes, explain:

____

____

____

____

11. In terms of reducing crew workload, which system was most effective?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Explain:

____

____

____

12. Overall, which system would you prefer in future aircraft?

☐	☐	☐	☐	☐
EMADS Significantly Better	EMADS Slightly Better	No Difference	Conventional Slightly Better	Conventional Significantly Better

Explain:

____

____

____

APPENDIX D
ANALYSIS OF VARIANCE
SUMMARY TABLES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	961849.72796	1	961849.72796	1812.20	0.0000
	ERROR	3715.33862	7	530.76266		
2.	DISPLAY	5138.44299	1	5138.44299	8.62	0.0218
	ERROR	4173.21925	7	596.17418		
3.	REPITITION	2780.71395	1	2780.71395	7.56	0.0285
	ERROR	2574.74943	7	367.82135		
4.	D X R	2136.94481	1	2136.94481	3.60	0.0995
	ERROR	4153.17858	7	593.31123		

ANOVA SUMMARY TABLE:
PRE-FLIGHT: NORMAL OPERATIONS

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	16120.43881	1	16120.43881	1665.83	0.0000
	ERROR	67.73983	7	9.67712		
2.	DISPLAY	0.00195	1	0.00195	0.00	0.9840
	ERROR	31.48122	7	4.49732		
3.	FAULT	35.59570	1	35.59570	7.08	0.0324
	ERROR	35.20489	7	5.02927		
4.	D X F	27.65820	1	27.65820	5.99	0.0442
	ERROR	32.30503	7	4.61500		

ANOVA SUMMARY TABLE:
PRE-FLIGHT: FAULT MONITORING
DETECTION TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	18556.03855	1	18556.03855	1425.28	0.0000
	ERROR	91.13470	7	13.01924		
2.	DISPLAY	0.19532	1	0.19532	0.05	0.8301
	ERROR	27.57468	7	3.93924		
3.	FAULT	12.62532	1	12.62532	1.87	0.2139
	ERROR	47.30208	7	6.75744		
4.	D X F	58.59036	1	58.59036	9.30	0.0186
	ERROR	44.09477	7	6.29925		

ANOVA SUMMARY TABLE:
PRE-FLIGHT: FAULT MONITORING
RESPONSE TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	1537665.91872	1	1537665.91872	3589229.00	0.0000
	GROUP	0.09570	1	0.09570	0.22	0.6532
	ERROR	2.57047	6	0.42841		
2.	DISPLAY	2.23135	1	2.23135	15.68	0.0074
	D X G	1.55320	1	1.55320	10.92	0.0163
	ERROR	0.85360	6	0.14227		
3.	STRATEGY	1.59758	1	1.59758	10.35	0.0182
	S X G	0.03445	1	0.03445	0.22	0.6533
	ERROR	0.92608	6	0.15435		
4.	D X S	0.00633	1	0.00633	0.05	0.8235
	D X S X G	0.48758	1	0.48758	4.18	0.0868
	ERROR	0.69922	6	0.11654		
5.	TARGET	210.89434	1	210.89434	1892.59	0.0000
	T X G	0.31008	1	0.31008	2.78	0.1463
	ERROR	0.66859	6	0.11143		
6.	D X T	0.07508	1	0.07508	0.20	0.6731
	D X T X G	0.08507	1	0.08507	0.22	0.6537
	ERROR	2.29296	6	0.38216		
7.	S X T	0.59132	1	0.59132	3.18	0.1248
	S X T X G	0.86132	1	0.86132	4.63	0.0749
	ERROR	1.11546	6	0.18591		
8.	D X S X T	0.04883	1	0.04883	0.34	0.5833
	D X S X T X G	0.27196	1	0.27196	1.87	0.2204
	ERROR	0.87235	6	0.14539		

ANOVA SUMMARY TABLE:
MEAN N_1 SETTING AT 80 KNOTS

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
9.	REPITITION	0.04882	1	0.04882	1.30	0.2972
	R X G	0.14446	1	0.14446	3.85	0.0972
	ERROR	0.22485	6	0.03747		
10.	D X R	0.14445	1	0.14445	0.60	0.4665
	D X R X G	0.00945	1	0.00945	0.04	0.8489
	ERROR	1.43422	6	0.23904		
11.	S X R	0.00945	1	0.00945	0.03	0.8691
	S X R X G	0.37195	1	0.37195	1.16	0.3220
	ERROR	1.91674	6	0.31946		
12.	D X S X R	0.21945	1	0.21945	3.86	0.0971
	D X S X R X G	0.02258	1	0.02258	0.40	0.5518
	ERROR	0.34110	6	0.05685		
13.	T X R	0.00195	1	0.00195	0.01	0.9205
	T X R X G	0.53820	1	0.53820	2.98	0.1350
	ERROR	1.08296	6	0.18049		
14.	S X T X T	0.02258	1	0.02258	0.39	?
	S X T X R X G	0.10695	1	0.10695	1.84	?
	ERROR	0.34860	6	0.05810		
1.5	D X S X T X R	0.73508	1	0.73508	6.59	0.0425
	D X S X T X R X G	0.04883	1	0.04883	0.44	0.5328
	ERROR	0.66923	6	0.11154		

ANOVA SUMMARY TABLE:
MEAN N_1 SETTING AT 80 KNOTS (Continued)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	1529981.33531	1	1529981.33531	3073424.00	0.0000
	GROUP	0.11282	1	0.11282	0.23	0.6509
	ERROR	2.98686	6	0.49781		
2.	DISPLAY	0.75031	1	0.75031	2.29	0.1881
	D X G	0.52531	1	0.52531	1.60	0.2525
	ERROR	1.96686	6	0.32781		
3.	STRATEGY	0.75031	1	0.75031	3.87	0.0968
	S X G	0.00031	1	0.00031	0.00	0.9693
	ERROR	1.16438	6	0.19406		
4.	D X S	0.26281	1	0.26281	1.75	0.2342
	D X S X G	0.02531	1	0.02531	0.17	0.6958
	ERROR	0.90188	6	0.15031		
5.	TARGET	216.31983	1	216.31983	2868.33	0.0000
	T X G	0.12500	1	0.12500	1.66	0.2454
	ERROR	0.45250	1	0.07542		
6.	D X T	0.08000	1	0.08000	0.28	0.6159
	D X T X G	0.01125	1	0.01125	0.04	0.8493
	ERROR	1.71625	6	0.28604		
7.	S X T	0.06125	1	0.06125	0.79	0.4076
	S X T X G	0.18000	1	0.18000	2.33	0.1778
	ERROR	04.46374	6	0.07729		
8.	D X S X T	0.36125	1	0.36125	2.34	0.1772
	S X S X T X G	0.21125	1	0.21125	1.37	0.2867
	ERROR	0.92749	6	0.15458		

ANOVA SUMMARY TABLE:
MEAN N_1 SETTING AT V_1

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
9.	REPITITION	0.01531	1	0.01531	0.59	0.4731
	R X G	0.01531	1	0.01531	0.59	0.4731
	ERROR	0.15687	6	0.02615		
10.	D X R	0.02531	1	0.02531	0.13	0.7273
	D X R X G	0.34031	1	0.34031	1.80	0.2287
	ERROR	1.13687	6	0.18948		
11.	S X R	0.07031	1	0.07031	0.32	0.5933
	S X R X G	0.11281	1	0.11281	0.51	0.5019
	ERROR	1.32687	6	0.22115		
12.	D X S X R	0.30032	1	0.30032	7.08	0.0374
	D X S X R X L	0.30032	1	0.30032	4.61	0.0755
	ERROR	0.25438	6	0.04240		
13.	T X R	0.06125	1	0.06125	0.36	0.5687
	T X R X G	0.08000	1	0.08000	0.47	0.5166
	ERROR	1.01124	6	0.16854		
14.	S X T X R	0.0	1	0.0	0.0	?
	S X T X R X G	0.02000	1	0.02000	1.71	?
	ERROR	0.07000	6	0.01167		
15.	D X S X F X R	0.50000	1	0.50000	4.42	0.0802
	D X S X T X R X G	0.06125	1	0.06125	0.54	0.4896
	ERROR	0.67874	6	0.11312		

ANOVA SUMMARY TABLE:
MEAN N_1 SETTING AT V_1 (Continued)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	12.56696	1	12.56696	976.49	0.0000
	GROUP	0.01741	1	0.01741	1.35	0.2889
	ERROR	0.07722	6	0.01287		
2.	DISPLAY	0.22604	1	0.22604	3.55	0.1084
	D X G	0.14412	1	0.14412	2.27	0.1830
	ERROR	0.38163	6	0.06361		
3.	STRATEGY	0.35733	1	0.35733	22.06	0.0033
	S X G	0.05400	1	0.05400	3.33	0.1177
	ERROR	0.09720	6	0.01620		
4.	D X S	0.19243	1	0.19243	2.56	0.1610
	D X S X G	0.10805	1	0.10805	1.43	0.2761
	ERROR	0.45182	6	0.07530		
5.	TARGET	0.05318	1	0.05318	1.97	0.2104
	T X G	0.03931	1	0.03931	1.45	0.2734
	ERROR	0.16227	6	0.02704		
6.	D X T	0.03764	1	0.03764	0.38	0.5627
	D X T X G	0.13397	1	0.13397	1.34	0.2918
	ERROR	0.60206	6	0.10034		
7.	S X T	0.22655	1	0.22655	5.75	0.0534
	S X T X G	0.03109	1	0.03109	0.79	0.4085
	ERROR	0.23634	6	0.03939		
8.	D X S X T	0.03635	1	0.03635	0.57	0.4805
	D X S X T X G	0.00059	1	0.00059	0.01	0.9267
	ERROR	0.38561	6	0.06427		

ANOVA SUMMARY TABLE:
$|N_1, \text{ at } V_1| - |N_1 \text{ at 80 Kts}|$

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
9.	REPITITION	0.00229	1	0.00229	0.05	0.8368
	R X G	0.01677	1	0.01677	0.34	0.5814
	ERROR	0.29638	6	0.04940		
10.	D X R	0.02271	1	0.02271	1.41	0.2804
	D X R X G	0.25499	1	0.25499	15.80	0.0073
	ERROR	0.09684	6	0.01614		
11.	S X R	0.08973	1	0.08973	2.06	0.2017
	S X R X G	0.03435	1	0.03435	0.79	0.4092

ANOVA SUMMARY TABLE:

$|N_1$, at $V_1| - |N_1$ at 80 Kts$|$ (Continued)

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
12.	D X S X R	0.00051	1	0.00051	0.02	0.8874
	D X S X R X G	0.18735	1	0.18735	8.05	0.0296
	ERROR	0.13957	6	0.02326		
13.	T X R	0.06068	1	0.06068	2.07	0.2001
	T X R X G	0.21020	1	0.21020	7.18	0.0366
	ERROR	0.17574	6	0.02929		
14.	S X T X R	0.05036	1	0.05036	1.97	0.2115
	S X T X R X G	0.15036	1	0.15036	5.90	0.0513
	ERROR	0.15300	6	0.02550		
15.	D X S X T X R	0.01003	1	0.01003	0.23	0.6462
	D X S X T X R X G	0.23727	1	0.23727	5.52	0.0571
	ERROR	0.25787	6	0.04298		

ANOVA SUMMARY TABLE:
$|N_1$, at $V_1| - |N_1$ at 80 Kts$|$ (Continued)

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
MEAN	86351.27062	1	86351.27062	56.60	0.0003
GROUP	1703.82023	1	1703.82023	1.12	0.3313
ERROR	9153.29675	6	1525.54946		
DISPLAY	5087.88296	1	5087.88296	14.67	0.0087
D X G	643.50776	6	643.50776	1.86	0.2221
ERROR	2081.29682	6	346.88280		
FAULT	3071.32020	1	3071.32030	4.08	0.0898
F X G	146.63279	1	146.63279	0.19	0.6743
ERROR	4512.73431	6	752.12239		
D X F	328.32035	1	328.32035	1.88	0.2195
D X F X G	453.75777	1	453.75777	2.60	0.1582
ERROR	1048.10928	6	174.68488		

TAKE-OFF: FAULT MONITORING
DETECTION TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	177950.83618	1	177950.83618	64.52	0.0002
	GROUP	3817.19531	1	3817.19531	1.38	0.2840
	ERROR	16549.29688	6	2758.21615		
2.	DISPLAY	4644.07031	1	4644.07031	12.00	0.0134
	D X G	492.19531	1	492.19531	1.27	0.3024
	ERROR	2321.17187	6	386.86198		
3.	FAULT	2529.38281	1	2529.38281	2.21	0.1878
	F X G	103.32031	6	1145.24740		
4.	D X F	984.57031	1	984.57031	17.27	0.0060
	D X F X G	1345.50781	1	1345.50781	23.60	0.0028
	ERROR	342.10937	6	57.01823		

TAKE-OFF: FAULT MONITORING
RESPONSE TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	4663.36364	1	4663.36364	125.92	0.0000
	GROUP	0.09031	1	0.09031	0.00	0.9622
	ERROR	222.20156	6	37.03359		
2.	DISPLAY	133.25273	1	133.25273	5.64	0.0551
	D X G	121.29012	1	121.29012	5.13	0.0640
	ERROR	141.74429	6	23.62405		
3.	REPITITION	5.69530	1	5.69530	7.10	0.0373
	R X G	1.95032	1	1.95032	2.43	0.1699
	ERROR	4.81187	6	0.80198		
4.	D X R	2.25780	1	2.25780	1.59	0.2541
	D X R X G	1.95031	1	1.95031	1.37	0.2856
	ERROR	8.51936	6	1.41989		

ANOVA SUMMARY TABLE
DEGREE OF TAKE-OFF N_1, EXCEEDANCE

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	9031.67668	1	9031.67668	503.51	0.0000
	GROUP	70.21111	1	70.21111	3.91	0.0952
	ERROR	107.62377	6	17.93730		
2.	DISPLAY	44.17991	1	44.17991	1.65	0.2461
	D X G	44.65128	1	44.65128	1.67	0.2439
	ERROR	160.50363	6	26.75061		
3.	REPITITION	60.49981	1	60.49981	14.63	0.0087
	R X G	0.15125	1	0.15125	0.04	0.8546
	ERROR	24.81374	6	4.13562		
4.	D X R	1.12499	1	1.12499	0.19	0.6764
	D X R X G	24.85124	1	24.85124	4.25	0.0850
	ERROR	35.10876	6	5.85146		

ANOVA SUMMARY TABLE
DEGREE OF TAKE-OFF EGT EXCEEDANCE

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	5115.28806	1	5115.28806	419.67	0.000
	GROUP	15.12237	1	15.12237	1.24	0.3080
	ERROR	73.13280	6	12.18889		
2.	DISPLAY	5.45807	1	5.45807	0.55	0.4858
	D X G	36.31563	1	36.31563	3.67	0.1040
	ERROR	59.40645	6	9.90108		
3.	FAULT	249.99549	1	249.99549	13.10	0.0111
	F X G	43.21417	1	43.21417	2.26	0.1831
	ERROR	114.53911	6	19.08985		
4.	D X F	3.15507	1	3.15507	0.40	0.5523
	D X F X G	12.68247	1	12.68247	1.59	0.2538
	ERROR	47.79092	6	7.96515		
5.	.EPITITION	3.99500	1	3.99500	0.31	0.5951
	R X G	29.82522	1	29.82522	2.35	0.1762
	ERROR	76.15847	6			
6.	D X R	37.65352	1	37.65352	20.08	0.0042
	D X R X G	12.77169	1	12.77169	6.81	0.0401
	ERROR	11.25100	6	1.87517		
7.	F X R	1.34850	1	1.34850	0.36	0.5701
	F X R X G	8.56292	1	8.56292	2.29	0.1809
	ERROR	22.42855	6	3.73809		
8.	D X F X R	4.10568	1	4.10568	0.50	0.5060
	D X F X R X G	15.29787	1	15.29787	1.86	0.2212
	ERROR	49.26945	6	8.21157		

IN-FLIGHT: FAULT MONITORING
DETECTION TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	7433.02467	1	7433.02467	265.67	0.0000
	GROUP	11.86802	1	11.86802	0.42	0.5390
	ERROR	167.87121	6	27.97853		
2.	DISPLAY	0.16402	1	0.16402	0.01	0.9186
	D X G	14.97689	1	14.97689	1.04	0.3478
	ERROR	86.64409	6	14.44068		
3.	FAULT	265.85287	1	265.85287	11.40	0.0149
	F X G	45.63000	1	45.63000	1.96	0.2114
	ERROR	139.94314	6	23.32386		
4.	D X F	10.04889	1	10.04889	1.37	0.2861
	D X F X G	37.88400	1	37.88400	5.17	0.0634
	ERROR	43.99061	6	7.33177		
5.	REPITITION	2.00931	1	2.00931	0.21	0.6637
	R X G	37.11854	1	37.11854	3.86	0.0971
	ERROR	57.69692	6	9.61615		
6.	D X R	15.54328	1	15.54328	5.01	0.0664
	D X R X G	19.29405	1	19.29405	6.23	0.0468
	ERROR	18.59667	6	3.09944		
7.	F X R	4.59030	1	4.59030	0.53	0.4948
	F X R X G	0.23281	1	0.23281	0.30	0.8754
	ERROR	52.15069	6	8.69178		
8.	D X F X R	5.79603	1	5.79603	0.62	0.4608
	D X F X R X G	9.87530	1	9.87530	1.06	0.3434
	ERROR	56.02714	6	9.33786		

IN-FLIGHT: FAULT MONITORING
RESPONSE TIMES

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1.	MEAN	1.92667	1	1.92667	107.22	0.0092
	ERROR	0.03594	2	0.01797		
2.	DISPLAY	0.00454	1	0.00454	1.96	0.2965
	ERROR	0.00463	2	0.00232		
3.	PHASE	0.03604	1	0.03604	0.49	0.5569
	ERROR	0.14749	2	0.07375		
4.	D X P	0.00427	1	0.00427	0.44	0.5772
	ERROR	0.01960	2	0.00980		
5.	FAULT	0.00070	1	0.00070	0.14	0.7468
	ERROR	0.01028	2	0.00514		
6.	D X F	0.00135	1	0.00135	0.46	0.5660
	ERROR	0.00582	2	0.00291		
7.	P X F	0.05227	1	0.05227	2.60	0.2479
	ERROR	0.04014	2	0.02007		
8.	D X P X F	0.00004	1	0.00004	0.01	0.9277
	ERROR	0.00713	2	0.00357		
9.	REPETITION	0.26209	3	0.08736	3.47	0.0908
	ERROR	0.15093	6	0.02515		
10.	D X R	0.00354	3	0.00118	0.28	0.8363
	ERROR	0.02502	6	0.00417		

TAKE-OFF AND IN-FLIGHT: HEADING DEVIATION
AVERAGE DEVIATIONS

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
11.	P X R	0.06034	3	0.02011	2.15	0.1946
	ERROR	0.05601	6	0.00933		
12.	D X P X R	0.00559	3	0.00186	0.43	0.7413
	ERROR	0.02621	6	0.00437		
13.	RF X R	0.00229	3	0.00076	0.04	0.9898
	ERROR	0.12636	6	0.02106		
14.	D X F X R	0.07516	3	0.02505	1.90	0.2314
	ERROR	0.07930	6	0.01322		
15.	P X F X R	0.02414	3	0.00805	1.12	0.4117
	ERROR	0.0430	6	0.00717		
16.	D X P X F X R	0.02465	3	0.00822	0.97	0.4677
	ERROR	0.05105	6	0.00851		

TAKE-OFF AND IN-FLIGHT: HEADING DEVIATION
AVERAGE DEVIATIONS (Continued)

APPENDIX E

DEBRIEFING QUESTIONNAIRE

PILOT RESPONSES/COMMENTS

QUESTIONNAIRE RESPONSE

Question: Which system is most effective for providing failure information during engine start up?

Response	Number of Respondents
EMADS Significantly Better	5
EMADS Slightly Better	4

Comments (paraphrased)	Number of Respondents
The presentation of engine parameters with EMADS is easier to monitor for abnormalities	4
EMADS gives more obtrusive indication of fault information	4
EMADS provides a useful checklist capability	3

Question: Which system best facilitates engine monitoring during start-up activities

Response	Number of Respondents
EMADS Significantly Better	3
EMADS Slightly Better	4
No Preference	1
No Response	1

Comments (paraphased)	Number of Respondents
Pertinent information is in closer proximity with EMADS	2
Better simplicity of presentation/logic with EMADS	1
Would like to have view of all engine parameters when in start mode, as with conventional dials/tapes.	1

Question: Which system best facilitates the accurate setting of take-off power?

Response	Number of Respondents
EMADS Significantly Better	8
EMADS Slightly Better	1

Comments (paraphrased)	Number of Respondents
EMADS provides a more noticeable target with chevron intensity change	6
EMADS display appears more precise and easily readable	3
Small digital figures in EMADS somewhat difficult to read	1
EMADS tolerance limits too large	1

Question: Which system best facilitates the monitoring of in-flight faults?

Response	Number of Respondents
EMADS Significantly Better	5
EMADS Slightly Better	2
Conventional Slightly Better	1
No Response	1

Comments (paraphrased)	Number of Respondents
EMADS provides better attention getting cues	6
Color would be a useful addition to EMADS	2
Less scanning required with EMADS because of automatic fault monitoring capability	1

Question: Which system is most effective in guiding corrective action?

Response	Number of Respondents
EMADS Significantly Better	5
EMADS Slightly Better	4

Comments (paraphrased)	Number of Respondents
EMADS provides checklist presentation	4
EMADS would be more effective if color was employed	1

AD-A145 901 A COMPARATIVE EVALUATION OF EMADS (ENGINE MONITORING AND DISPLAY SYSTEM) AND CONVENTIONAL ENGINE INSTRUMENTS (U) DOUGLAS AIRCRAFT CO LONG BEACH CA D A PO-CHEDLEY 2/2

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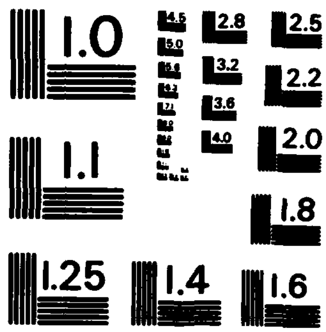

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Question: In terms of display clarity, which system is most effective?

Response	Number of Respondents
EMADS Significantly Better	6
EMADS Slightly Better	3

Comments (paraphrased)	Number of Respondents
EMADS is easier to read	2
The use of color would enhance the clarity of EMADS	1
By providing only necessary information, EMADS becomes the more desirable display	1

Question: In terms of reducing crew workload, which system was most effective?

Response	Number of Respondents
EMADS Significantly Better	7
EMADS Slightly Better	1
No Difference	1

Comments (paraphrased)	Number of Respondents
The automation that is part of EMADS is a significant worksaving element	1
EMADS does not require a high vigilance level	1
More information can be obtained in a shorter period of time with EMADS	1

Question: Overall, which system would you prefer in future aircraft?

Response	Number of Respondents
EMADS	9
Conventional	0

Comments (paraphrased)	Number of Respondents
Display and software provide for faster retrieval of necessary information	3
EMADS provide a better attention getting capability	2
EMADS provides all necessary information in the same location	2
EMADS should be reformatted to provide more readable and action oriented messages	1
The EMADS concept is excellent	1
The EMADS display is easier to read	1
A lower level of vigilance is required with EMADS	1